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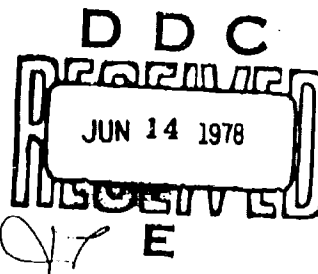
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**A COMPARISON OF MEASURED UPPER
AIR TEMPERATURES AND TEMPERATURES
DERIVED USING THE LAPSE RATE OF THE
US STANDARD ATMOSPHERE**

**AIRCRAFT COMPATIBILITY BRANCH
MUNITIONS DIVISION**

NOVEMBER 1977



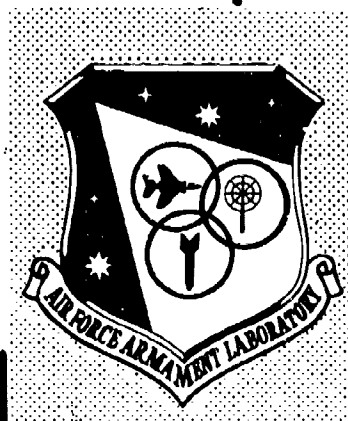
FINAL REPORT FOR PERIOD JUNE TO SEPTEMBER 1977

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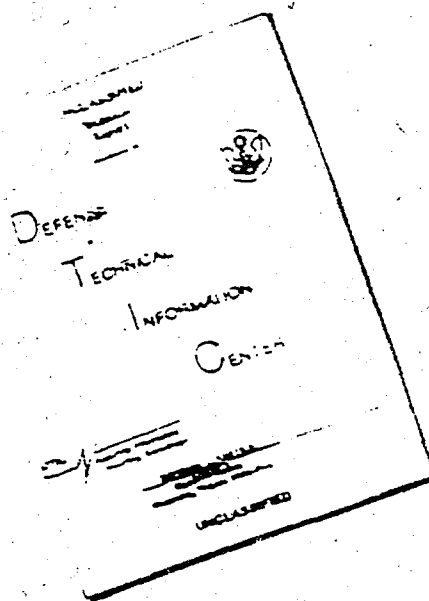
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Measured upper air temperatures at several locations were compared with temperatures derived using surface conditions and the lapse rate of the US Standard Atmosphere. The locations chosen were Helwan, Egypt; Mexico City, Mexico; Anchorage, Fairbanks, and Barrow, Alaska; Denver, Colorado; and Vandenberg Air Force Base and Edwards Air Force Base, California. It was shown that using a standard lapse rate can lead to large deviations from measured temperatures under realistic conditions. These conditions include temperature		

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Item 20 concluded: inversions, strong surface heating, non-standard tropopause heights, and high altitude locations. In several cases, differences between measured and derived temperatures exceeded 20°C. A method was presented which substantially reduced errors arising from low-level inversions by using a measured or forecasted temperature at 5000 feet above ground level.

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PREFACE

This study was conducted by the Aircraft Compatibility Branch of the Munitions Division under Project 25670218, Program Element 62602F, during the period from June to September 1977.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER:

William F. Brockman
WILLIAM F. BROCKMAN, Colonel, USAF
Chief, Munitions Division

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SECTION I

INTRODUCTION

One assumption in deriving upper-air temperatures is that the surface temperature along with a standard lapse rate can be used to obtain temperatures at altitude. Along with this goes the assumption of a standard tropopause height; the tropopause is defined as the height above which the temperature is approximately constant through the stratosphere.

These assumptions do not account for actual conditions such as strong surface heating, temperature inversions, and non-standard or ill-defined tropopause levels. Since some proposed methods used to calculate aerodynamic heating are based on temperatures derived using surface conditions and a standard lapse rate, it is desirable to investigate the validity of such an assumption. This report investigates the kinds of errors that can occur when temperatures are derived using the US Standard Atmosphere lapse rate and tropopause height.

SECTION II

DATA COLLECTION AND REDUCTION

Many meteorological stations throughout the world obtain upper air data through the use of radiosonde or rawinsonde equipment. Instruments trailing behind a balloon measure pressure, temperature, and humidity as they ascend through the atmosphere. By building up thickness layers with the hydrostatic equation, temperature, humidity parameters, and ambient pressure are measured at heights from the surface to near 100,000 feet above sea level.

The locations and times of the upper air data used in this study were picked for several reasons. The locations chosen represent various geographical and climatic regions, different seasons, and large variations from the standard lapse rate. Additionally, two locations selected are in close proximity but have very different surface temperatures.

Data for this report were obtained upon request from the USAF Environmental Technical Applications Center, Scott Air Force Base, Illinois. The standard reduction program used takes coded upper air data and calculates meteorological quantities from the surface to high altitude. Data is available every 1000 feet from the surface to 8000 feet above ground level (AGL), every 2000 feet from 8000 to 20,000 feet AGL, and every 5000 feet above 20,000 feet AGL. No data above 50,000 feet AGL was used due to the scarcity of aircraft flying above this level.

To obtain the derived profiles used as test cases, the following procedure was applied. Using surface temperature, the standard lapse rate of $6.5^{\circ}\text{C}/\text{kilometer}$ ($1.98^{\circ}\text{C}/1000$ feet) (Reference 1) was applied. The tropopause was assumed to be at the standard height of 11 kilometers (36,089 feet) above mean sea level (MSL), and all temperatures above this height were taken as constant to 50,000 feet AGL.

Differences between the measured and derived temperatures were calculated as

$$\begin{aligned} \text{AT (at altitude)} &= T \text{ (using standard lapse rate)} \\ &\quad - T \text{ (rawinsonde sounding)} \end{aligned}$$

or

$$\text{AT} = T_{\text{STD}_Y} - T_{\text{SOUND}}$$

¹Heights in this report are in units of geopotential feet. Since the maximum differences between geometric and geopotential altitude are only 120 feet at 50,000 feet MSL, they can be assumed equal to each other.

Table 1 lists each location examined, dates and times of the soundings, and height of the location above MSL.

Figures 1 to 24 show actual and derived temperature soundings along with differences between measured and derived temperatures.

TABLE 1. DATA LOCATIONS AND TIMES

Location	Elevation MSL (Feet)	Date	Time
Helwan, Egypt	456	1 July 1976	12Z
		1 July 1976	00Z
Mexico City, Mexico	7320	2 January 1976	00Z
		2 January 1976	12Z
Anchorage, Alaska	148	3 January 1976	12Z
		1 July 1976	00Z
Fairbanks, Alaska	443	3 January 1976	12Z
		1 July 1976	00Z
Barrow, Alaska	25	4 January 1976	00Z
		1 July 1976	00Z
Denver, Colorado	5285	5 July 1976	00Z
		3 January 1976	12Z
Edwards Air Force Base, California	2313	22 August 1977	10Z
Vandenberg Air Force Base, California	328	22 August 1977	12Z

SECTION III

DISCUSSION

Before examining each location, one point should be made. As will be evident from several of the plotted soundings, the slopes of the measured and derived curves are similar. Since the slope is an indication of the lapse rate, it appears that standard lapse is not a bad estimate in certain regions of the curves. An easier way to compare the lapse rates is to look at the plots of ΔT (standard lapse temperature - measured temperature) versus altitude. The more vertical the plot of ΔT , the closer the measured lapse is to the standard lapse. Any slope of the curve indicates departure from the standard lapse rate. A large change in the value of ΔT at higher altitudes indicates a non-standard tropopause height.

The reasoning behind the above is as follows: If ΔT does not change between two levels

$$\frac{\Delta T}{\Delta h} = \Delta T_{h_1} - \Delta T_{h_2} = 0 \quad (1)$$

$$\Delta T_{h_1} = \Delta T_{h_2} \quad (2)$$

where h_1, h_2 are two levels.

Using the definition of ΔT

$$\Delta T_{h_1} = T_{STD} \gamma_{h_1} - T_{SOUND_{h_1}} \quad (3)$$

$$\Delta T_{h_2} = T_{STD} \gamma_{h_2} - T_{SOUND_{h_2}} \quad (4)$$

Lapse rate is defined as

$$\gamma = - \frac{\Delta T}{\Delta h} \quad (5)$$

where $\gamma > 0$ for a temperature decrease upward.

Therefore, the temperature at h_2 is related to that at h_1 as follows:

$$T_{STD} \gamma_{h_2} = T_{STD} \gamma_{h_1} - \gamma_{STD} \Delta h \quad (6)$$

$$T_{\text{SOUND } h_2} = T_{\text{SOUND } h_1} - \gamma \Delta h \quad (7)$$

Putting Equations (6) and (7) into Equations (3) and (4) and substituting the results into Equation (2) gives

$$T_{\text{STD } h_1} - T_{\text{SOUND } h_1} = (T_{\text{STD } h_1} - \gamma_{\text{STD}} \Delta h) - (T_{\text{SOUND } h_1} - \gamma \Delta h) \quad (8)$$

or

$$\gamma \Delta h = \gamma_{\text{STD}} \Delta h \quad (9)$$

$$\gamma = \gamma_{\text{STD}} \quad (10)$$

Large changes in the value of ΔT of high altitude indicate non-standard tropopause height. The sounding temperature is still changing where the standard tropopause would indicate an isothermal layer. Conversely, the actual tropopause may occur below the standard height, causing large changes to occur at lower altitudes. These factors account for the large changes in magnitude and the change in sign of ΔT at higher altitudes seen on some of the plots.

Figures 1 to 4 present data from Helwan, Egypt. The daytime sounding (Figure 1) shows fairly good agreement between measured temperatures and temperatures based on the standard lapse rate (Figure 3), especially in the lower few thousand feet. This is expected due to boundary layer mixing caused by solar heating. Agreement is still fair in the middle level (10,000 to 30,000 feet). Errors are larger in the nighttime sounding (Figure 2) due to surface cooling. Figure 4 shows there was little temperature change between the times of the soundings except in the lower 4,000 feet. Using the standard lapse rate on both surface temperatures produces a temperature difference at all levels equal to the difference found on the surface, in this case, 10°C. The effects of a high tropopause are shown above 35,000 feet by large changes in the value of ΔT .

Figures 5 to 8 are based on Mexico City data. Both the day (Figure 5) and night (Figure 6) soundings show a similar ΔT trend above the lower few thousand feet. The nighttime cooling led to values very different in magnitude from those found in the daytime calculations. Large changes in the value of ΔT occur above 20,000 feet (Figure 7). This is due both to Mexico City's high elevation and a non-standard tropopause height.

Figure 8 is another plot of actual temperature differences between the soundings and those found using the standard lapse rate calculations. Actual changes are small, above 3,000 feet AGL, while the use of the standard lapse rate produces a uniform difference of 16°C.

Anchorage, Fairbanks, and Barrow, Alaska were used as examples of cold winter locations. These locations show a similar AT trend (Figures 11, 14, and 17) for the winter soundings (Figures 9, 12, and 15). Note the very large errors above the lower 2,000 to 3,000 feet. They are due to strong low-level temperature inversions where the temperature increases with height above the surface. The stronger the inversion (i.e., the greater the temperature increase with height), the larger the values of AT. Some values are in excess of 30°C.

The summer soundings (Figures 10, 13, and 16) give better agreement with calculations based on the standard lapse rate. In these cases, stronger heating wiped out the low-level inversions. Anchorage and Fairbanks show good agreement from the surface upward, while the weaker heating and low tropopause at Barrow still lead to considerable values of AT.

Denver, Colorado (Figures 18 to 20) is a good example of a high altitude location. The summer sounding (Figure 18) shows stronger lapse rates than standard. AT values (Figure 20) exceed 10°C from 10,000 feet upward. The winter sounding (Figure 19) is another example of the effects of a temperature inversion. Differences from standard lapse increase rapidly above the surface. Above 10,000 feet, the lapse rate is near standard, shown by the small changes in AT.

Figures 20 to 24 offer an example of two soundings taken from closely spaced locations. The data is from Edwards Air Force Base and Vandenberg Air Force Base in California. Vandenberg Air Force Base lies close to the coast, and Edwards Air Force Base is in the Mojave Desert. The measurements were from the morning soundings of 22 August 1977. Surface measurements were late afternoon (23Z) temperatures. Temperatures in the mixed layer below 3,000 feet AGL were adjusted to be consistent with afternoon surface temperatures. Little change was necessary for Vandenberg Air Force Base. An almost dry adiabatic rate (9.8°C/km) (2.99°C/1000 feet) was used for Edwards Air Force Base. Note that heights are above mean sea level to make comparison easier.

Figures 21 and 22 show measured and derived soundings. Figure 23 plots AT. AT values at Vandenberg Air Force Base are especially large due to a temperature inversion at about 1,500 feet MSL.

Actual temperature differences between the soundings are shown in Figure 24 along with differences found if a standard lapse rate is assumed. The standard lapse rate calculation gives a uniform difference of 24°C while actual differences are no more than 2°C above the surface mixing layer.

As is evident from the preceding figures and discussion, using a surface temperature along with the standard lapse rate and tropopause height can lead to large errors in the calculation of temperatures at altitude. Aside from desert or high altitude locations, the major problem seems to be temperature inversions and non-standard tropopause heights.

To investigate further, an alternate method of temperature derivation was tried. To eliminate the effects of low-level inversions, the temperature at 5,000 feet was assumed known. This information could come from actual measurement, or it could be forecasted with some degree of certainty. The results of applying the standard lapse rate to this temperature are shown in Figures 25 to 28 for four locations exhibiting low-level inversions. Values of ΔT are generally low, up to 30,000 feet. Above that height, two locations show larger values with the correction. This is due to a non-standard tropopause height. By estimating the tropopause height, high altitude errors are reduced. Forecasted tropopause height can also be obtained with little difficulty.

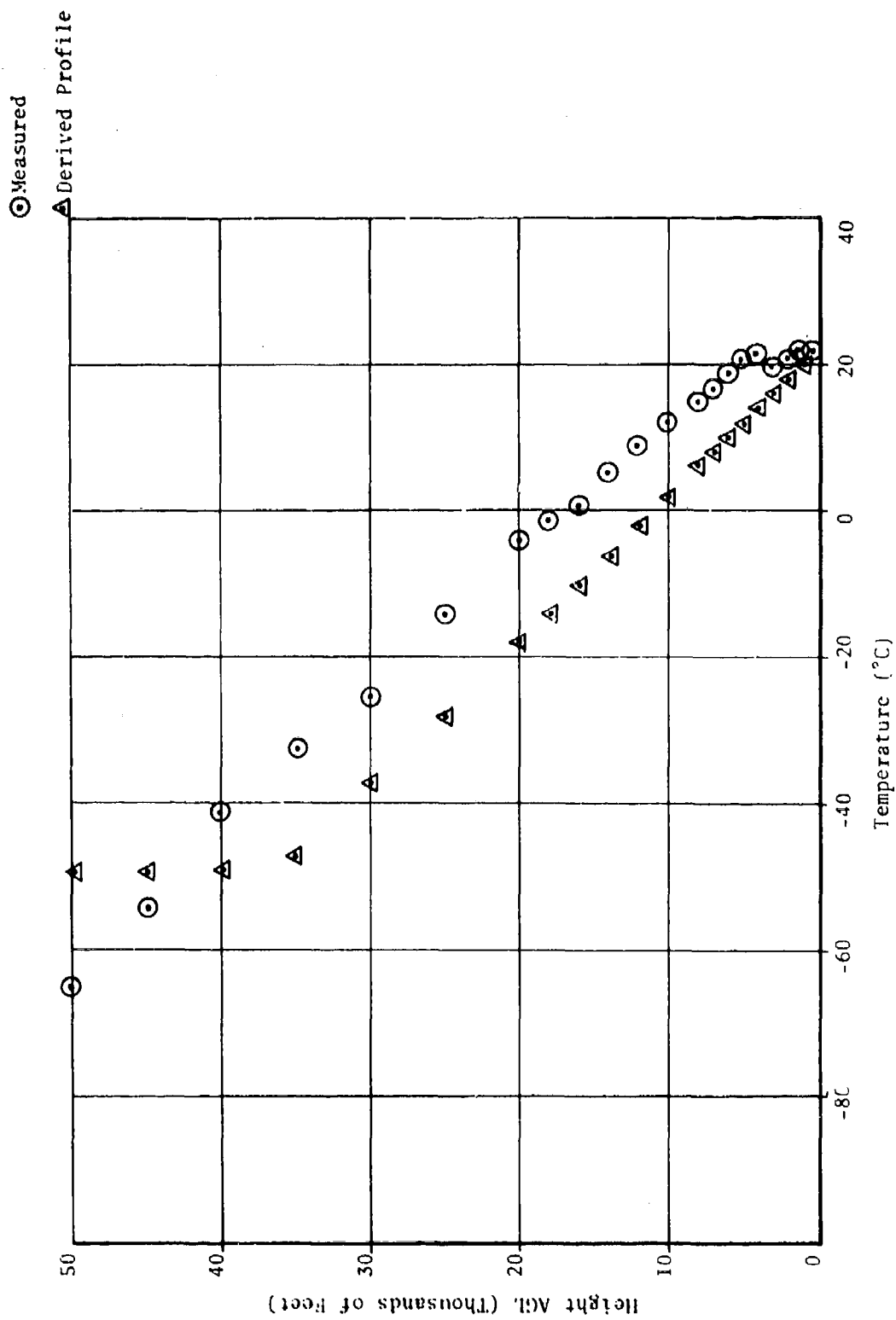


Figure 2. Temperature Sounding at Helwan, Egypt: 1 July 1976, 00Z

⊙ 1 July 1976, 12Z

△ 1 July 1976, 00Z

Height AGL (Thousands of Feet)

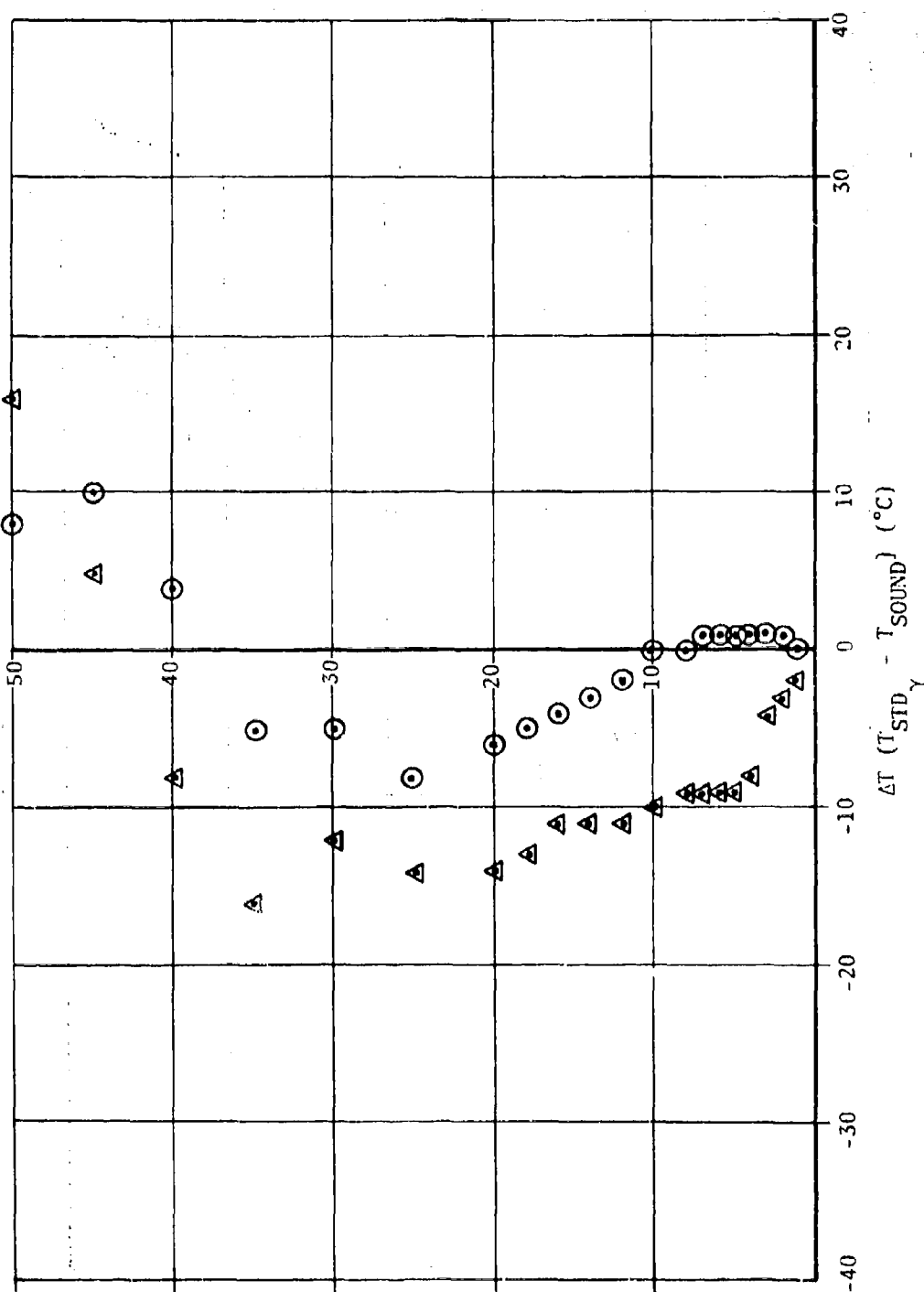


Figure 3. Temperature Differences Between Measured and Derived Soundings at Helwan, Egypt

○ From Soundings
 ▲ Using Derived Profiles

Height AGL (Thousands of Feet)

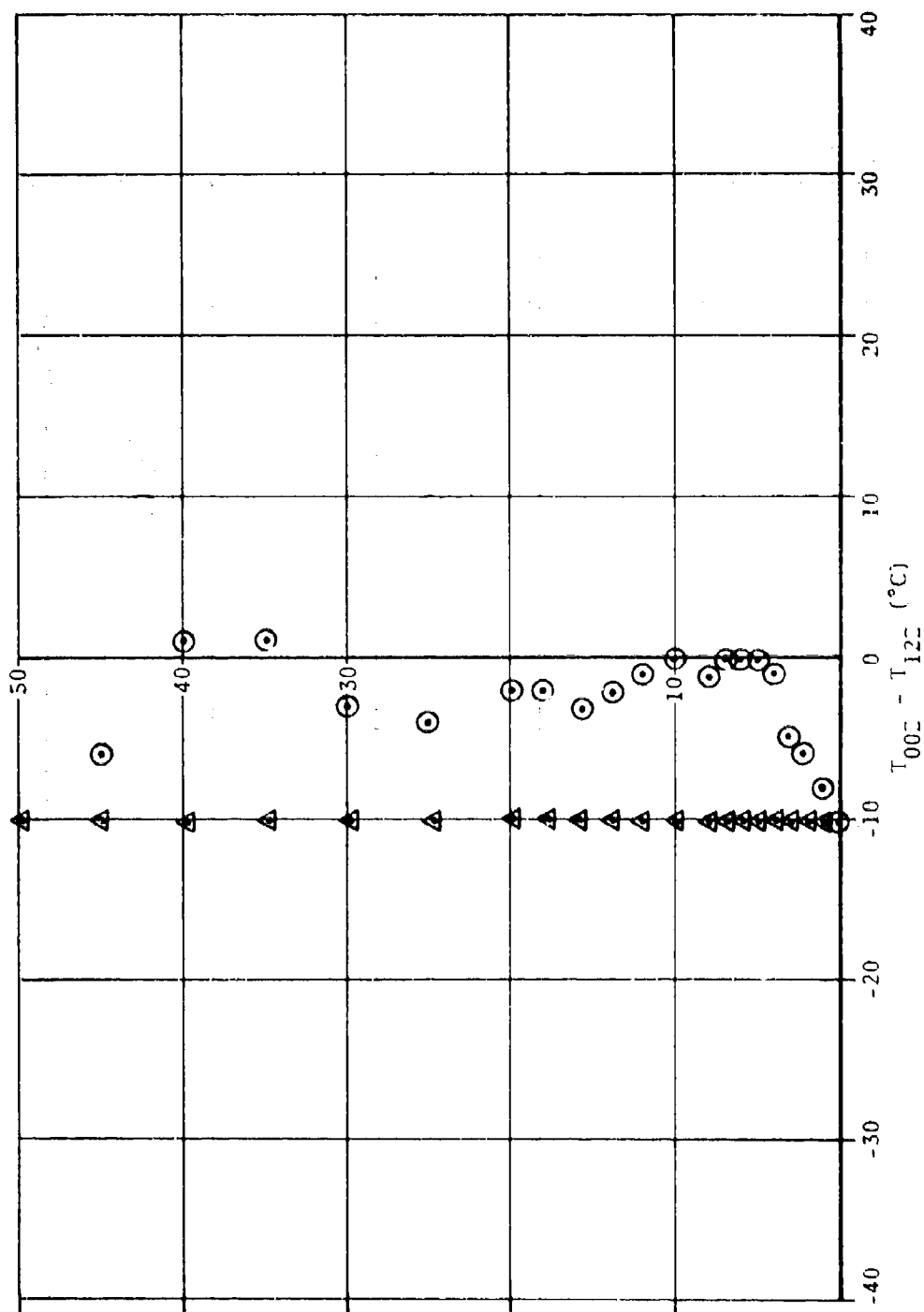


Figure 4. Time-Dependent Temperature Differences at Helwan, Egypt

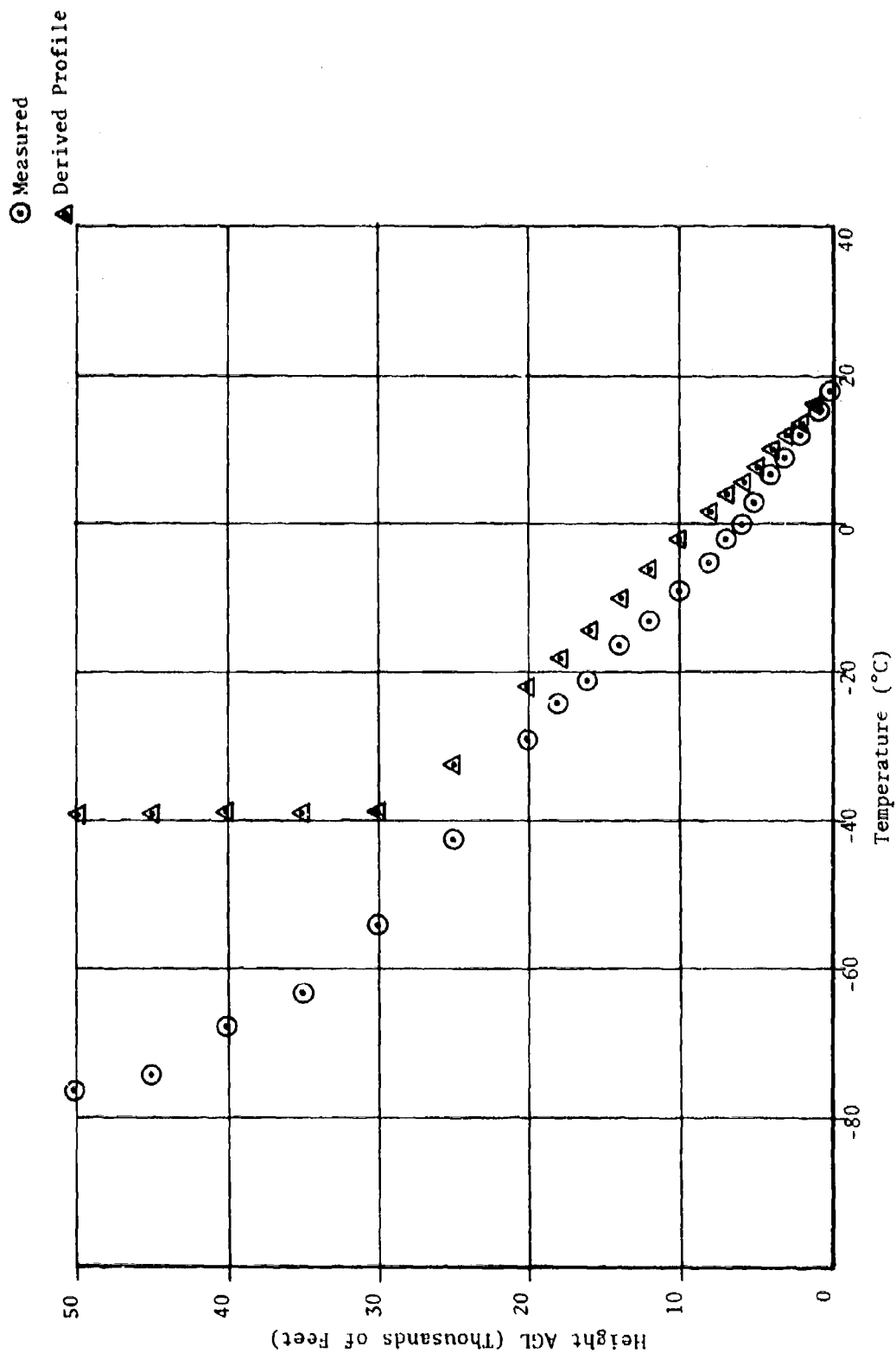


Figure 5. Temperature Sounding at Mexico City, Mexico: 2 January 1976, 00Z

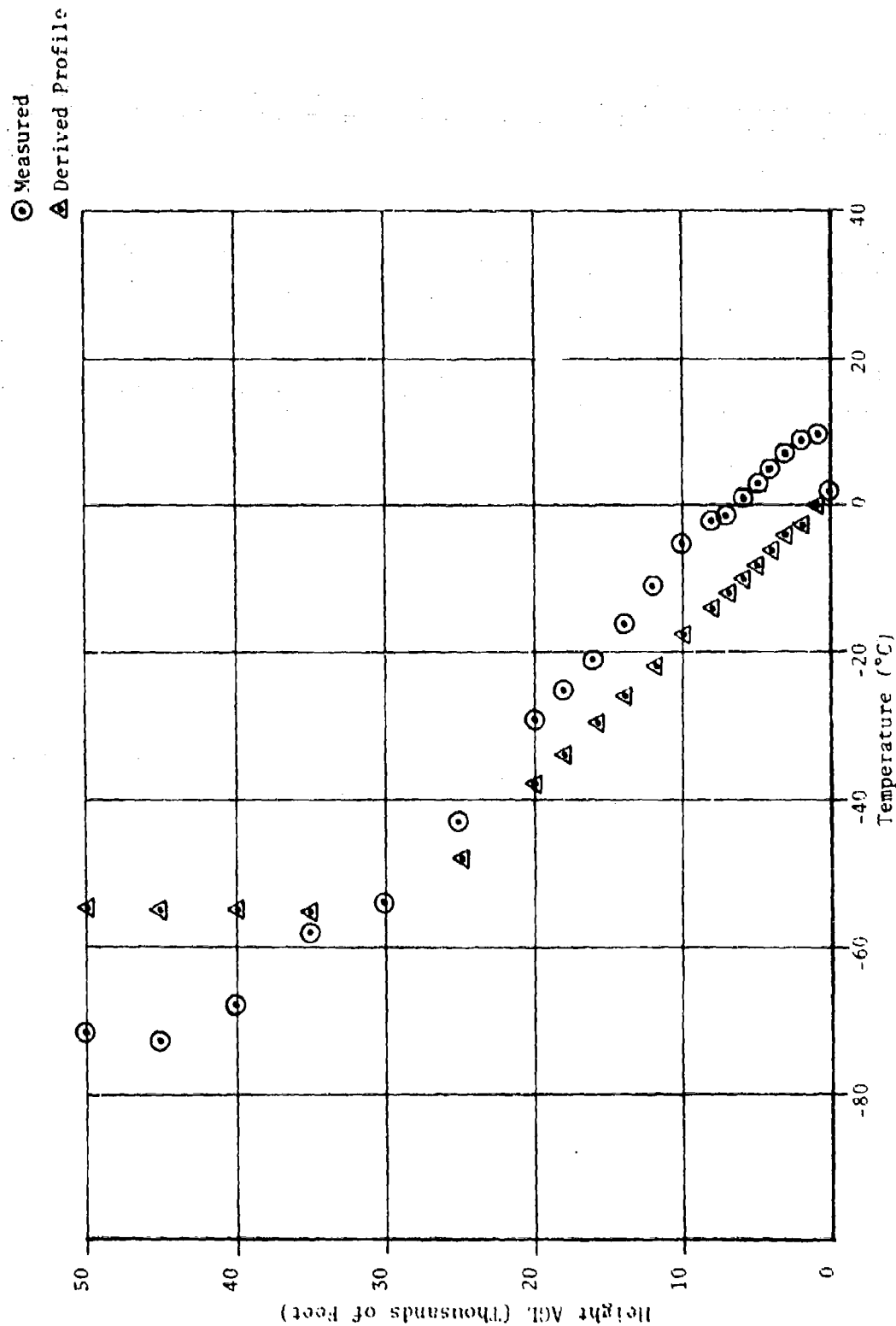


Figure 6. Temperature Sounding at Mexico City, Mexico: 2 January 1976, 12Z

⊙ 2 January 1976, 00Z
 Δ 2 January 1976, 12Z

Height AGL (Thousands of Feet)

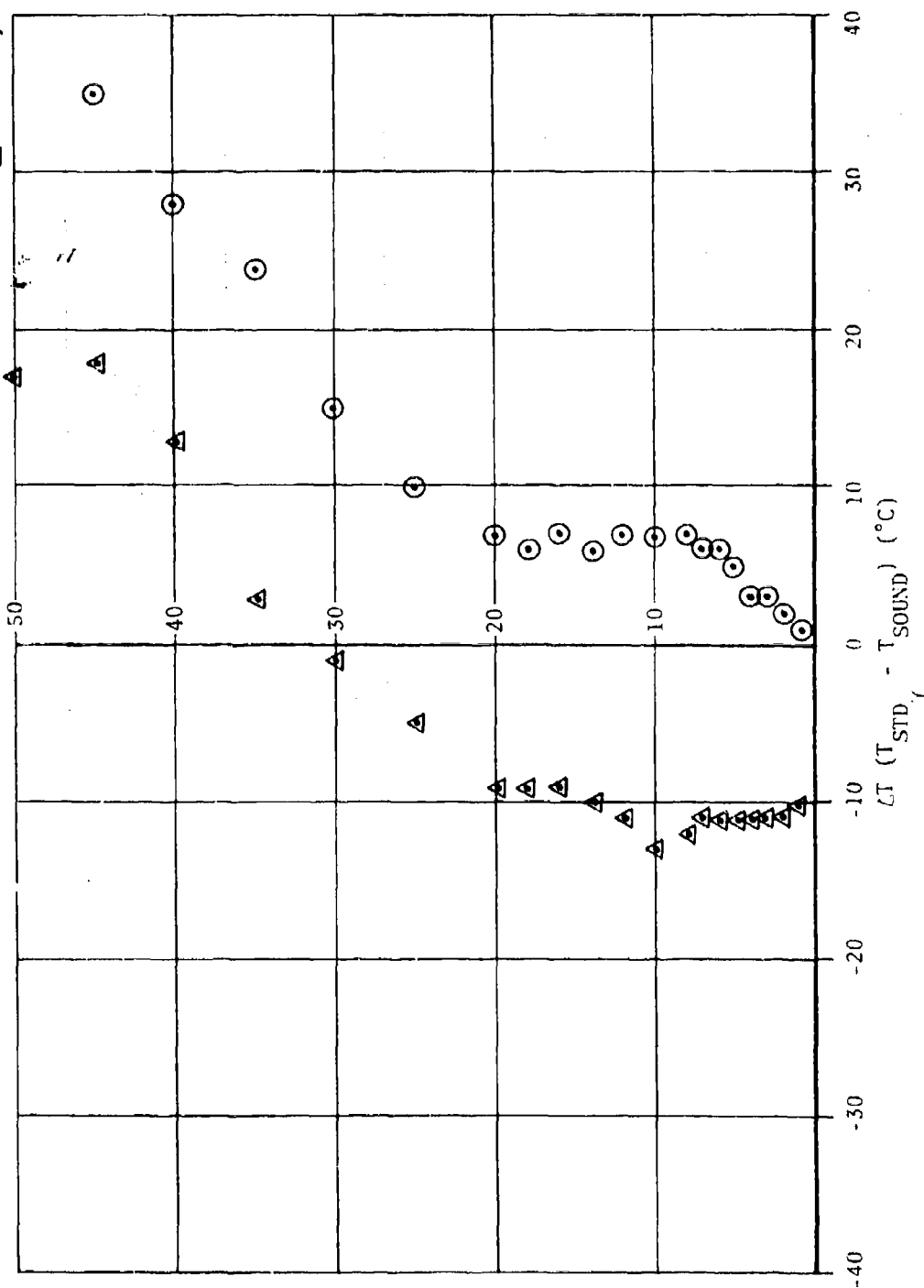


Figure 7. Temperature Differences Between Measured and Derived Soundings at Mexico City, Mexico

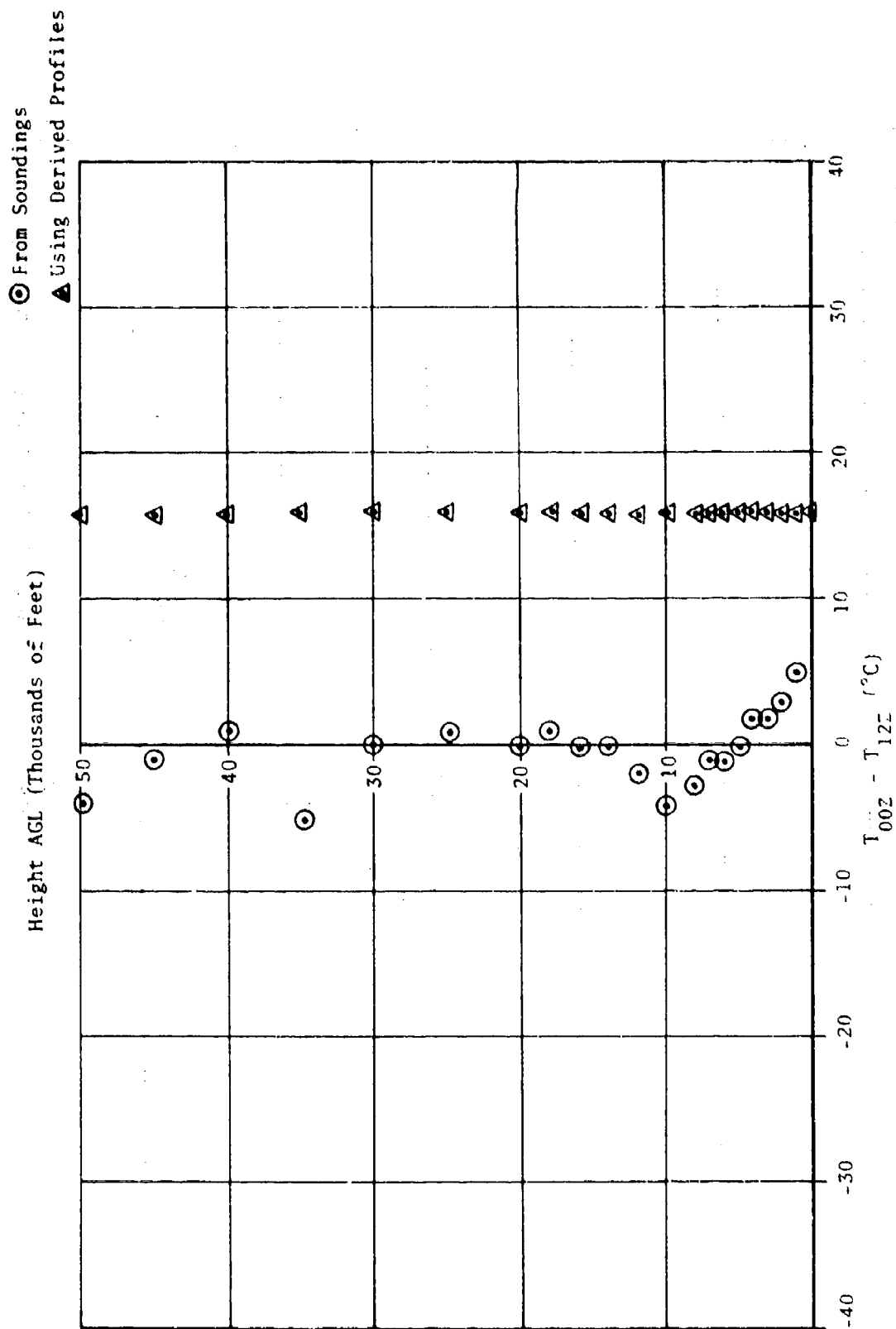


Figure 8. Time-Dependent Temperature Differences at Mexico City, Mexico

○ Measured
 △ Derived Profile

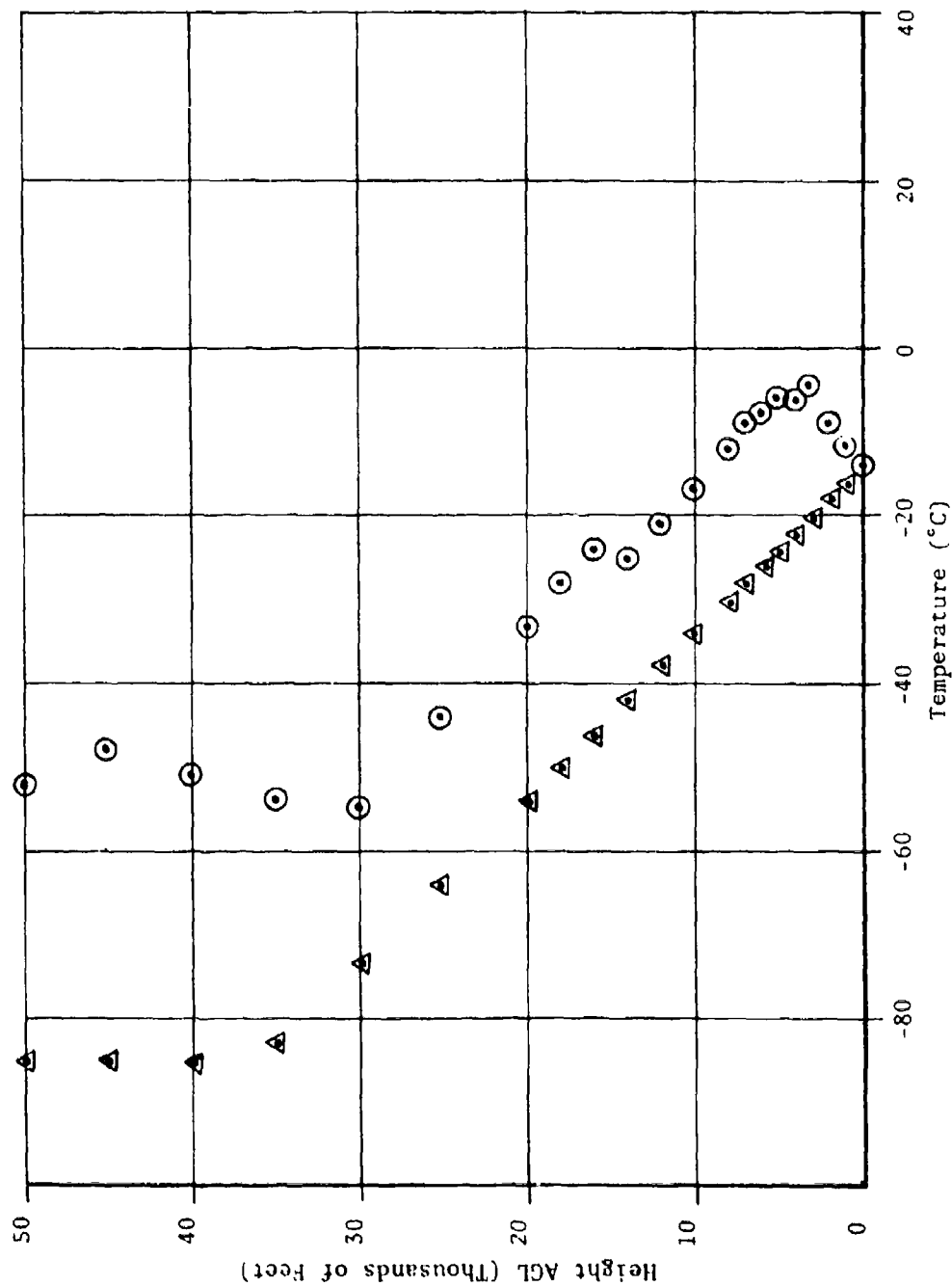


Figure 9. Temperature Sounding at Anchorage, Alaska: 3 January 1976, 12Z

⊙ Measured
 ▲ Derived Profile

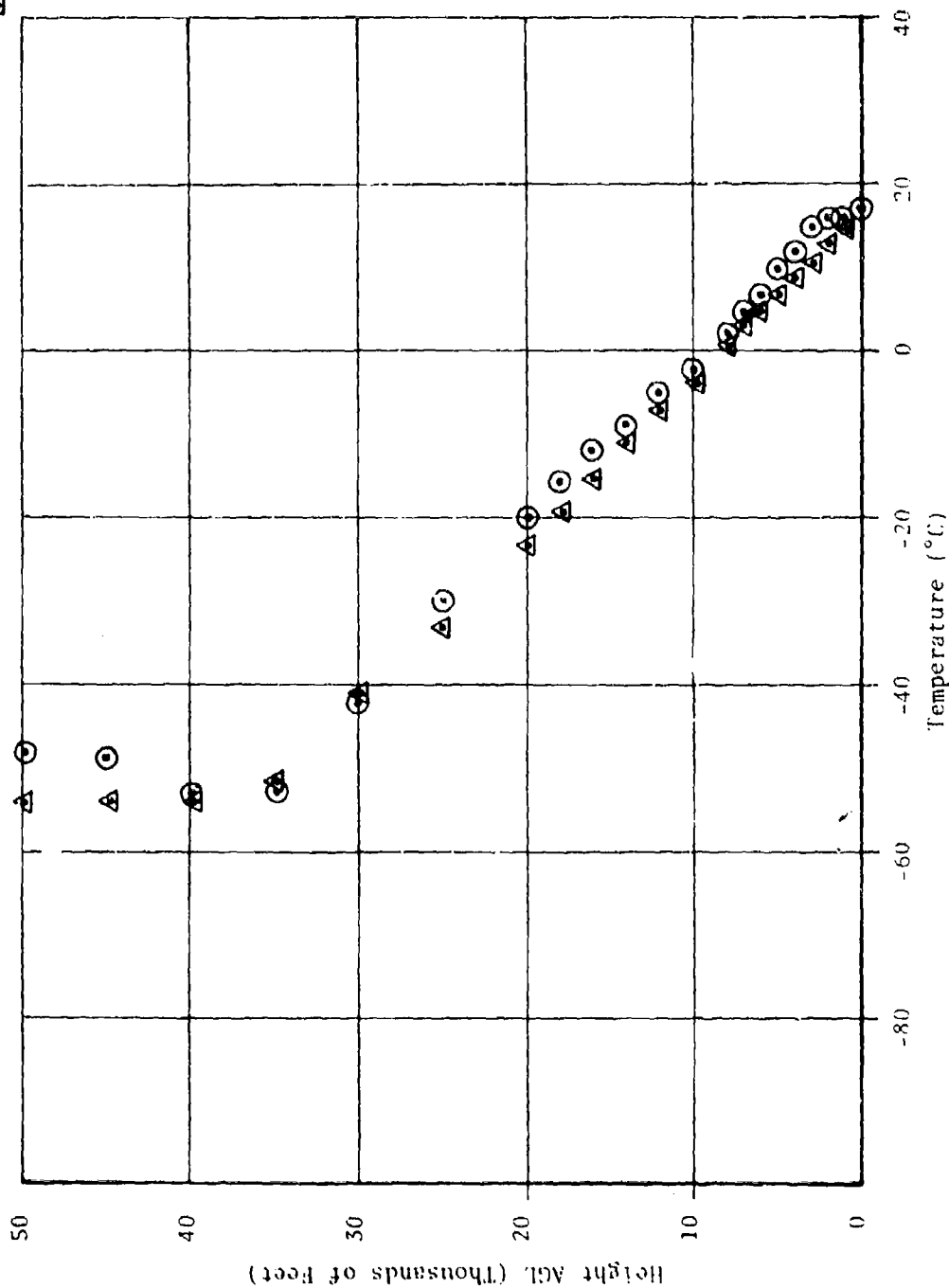


Figure 10. Temperature Sounding at Anchorage, Alaska: 1 July 1976, 00Z

⊙ 3 January 1976, 12Z
 ▲ 1 July 1976, 00Z

Height AGL (Thousands of Feet)

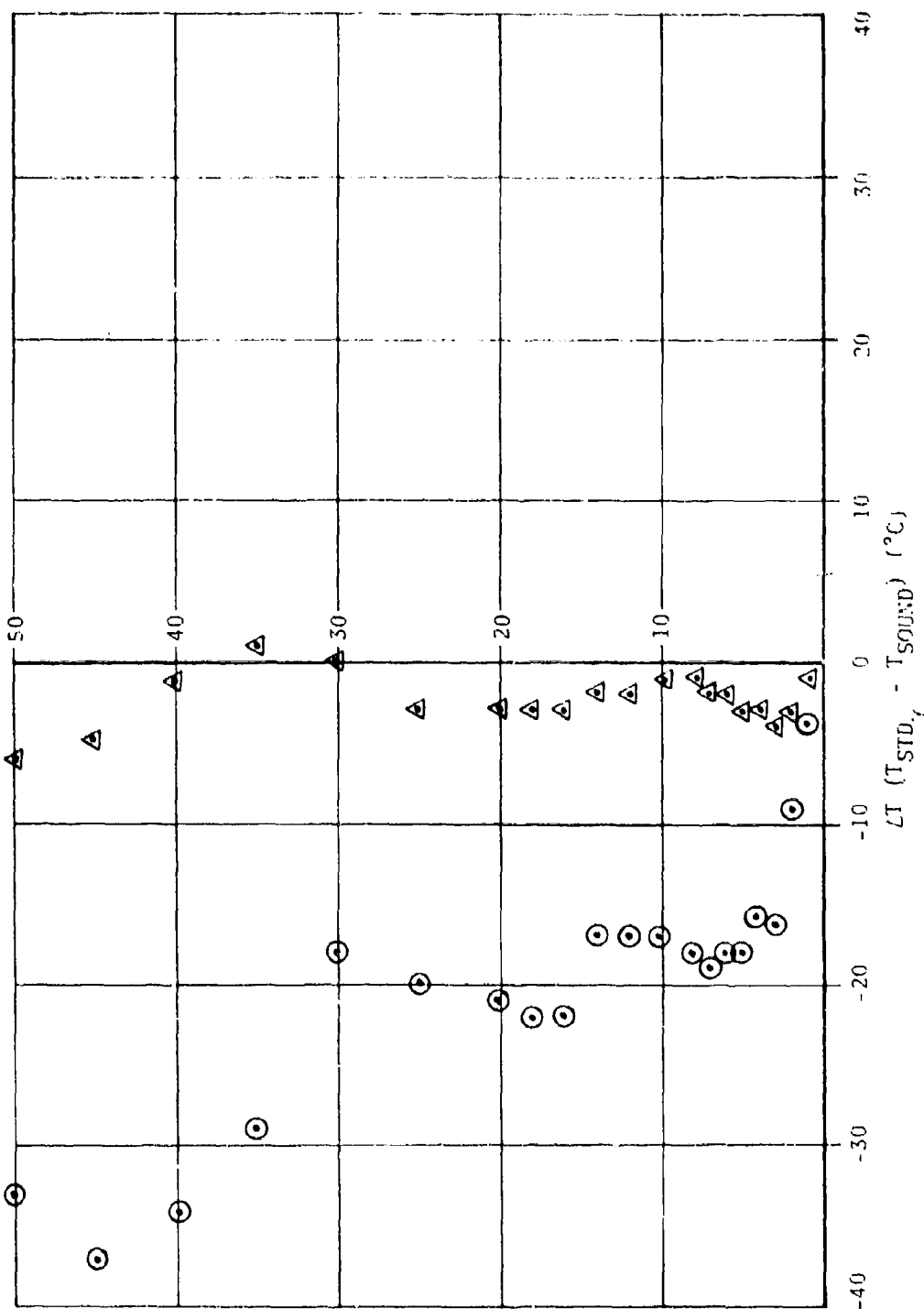


Figure 11. Temperature Differences Between Measured and Derived Soundings at Anchorage, Alaska

○ Measured
 ▲ Derived Profile

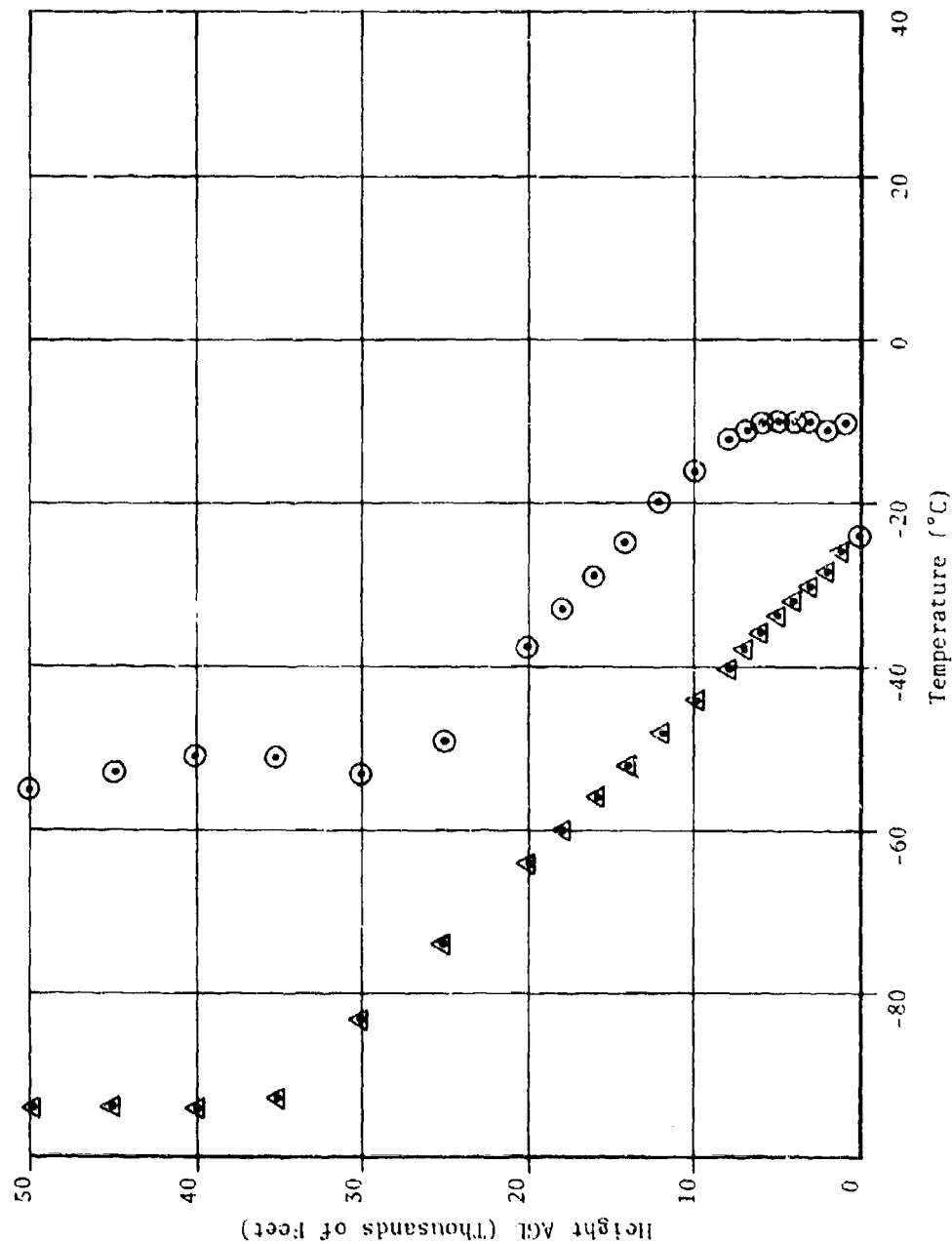


Figure 12. Temperature Sounding at Fairbanks, Alaska: 3 January 1976, 12Z

○ Measured
 ▲ Derived Profile

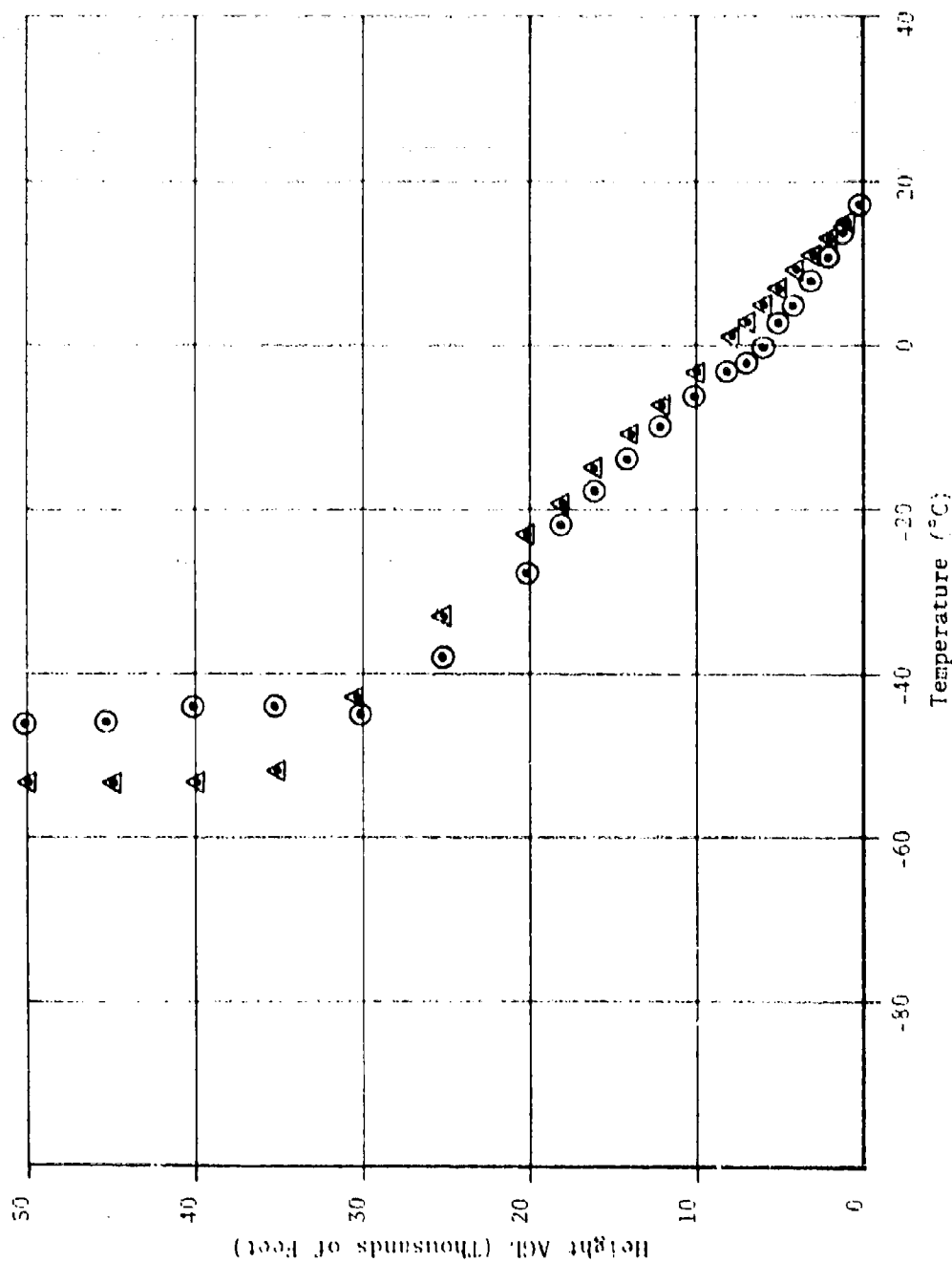


Figure 13. Temperature Sounding at Fairbanks, Alaska: 1 July 1976, 00Z

○ 3 January 1976, 12Z
 ▲ 1 July 1976, 00Z

Height ASL (Thousands of Feet)

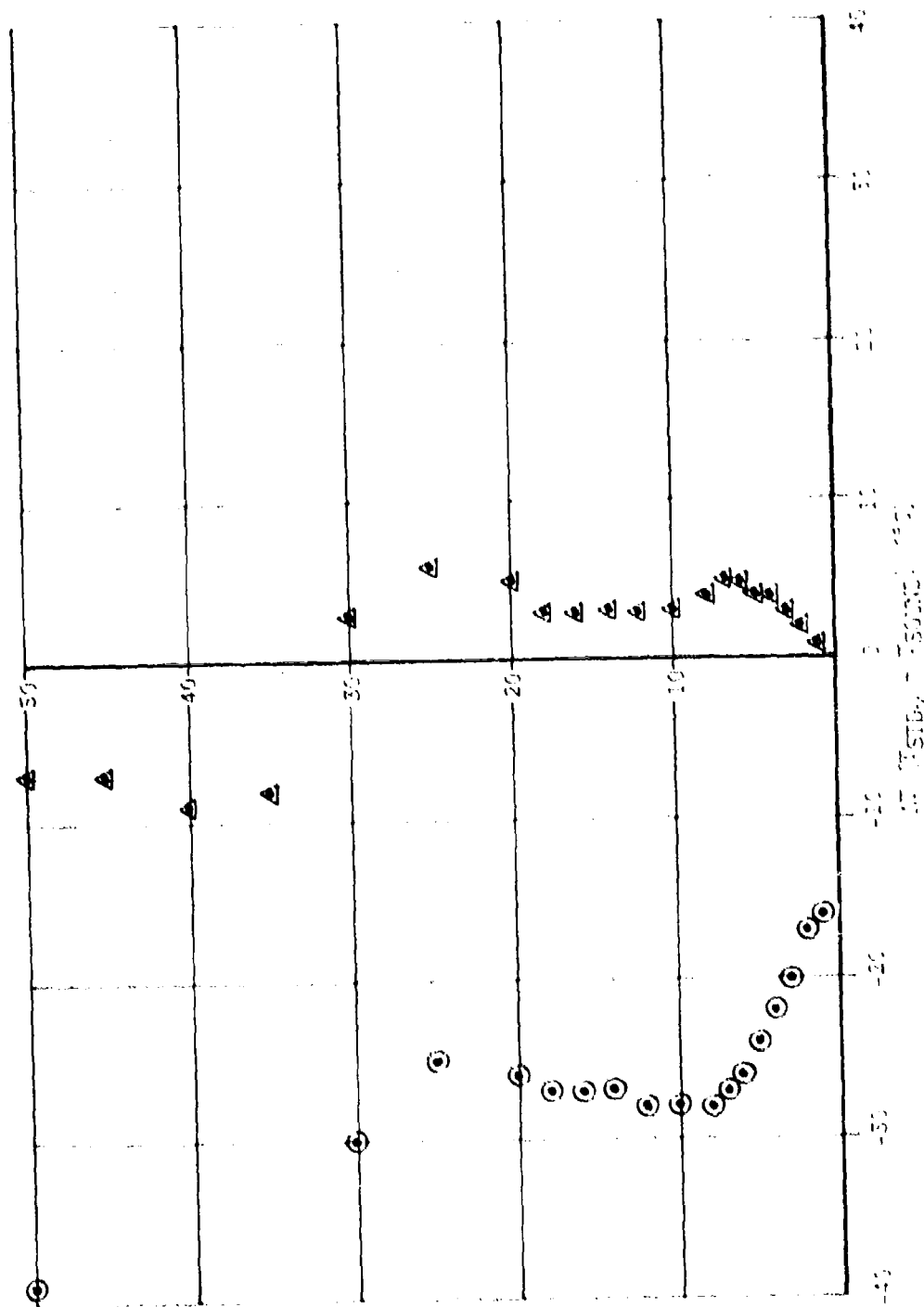


Figure 14. Temperature Differences Between Measured and Derived Soundings at Fairbanks, Alaska

○ Measured
 ▲ Derived Profile

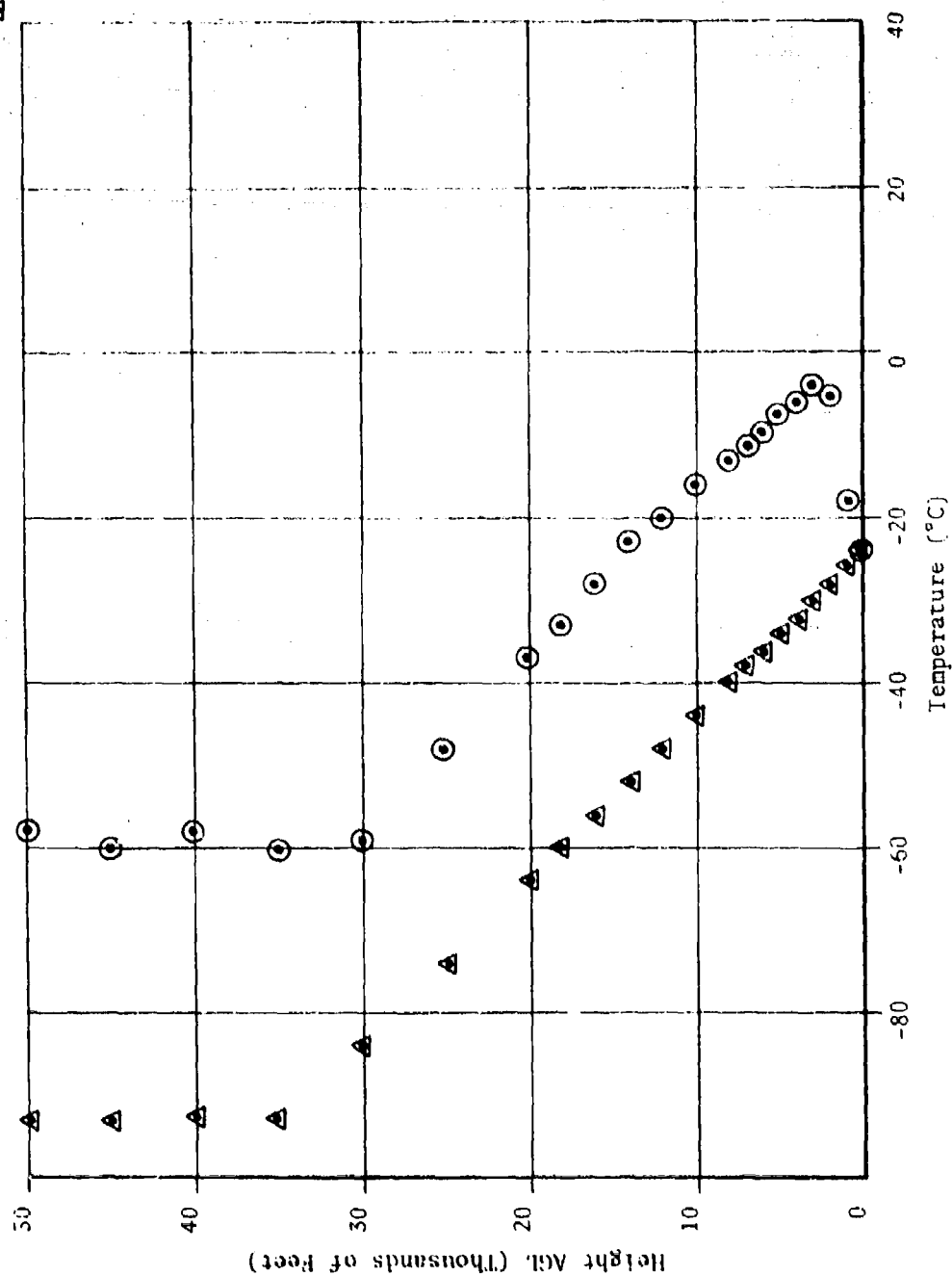


Figure 15. Temperature Sounding at Barrow, Alaska: 4 January 1976, 00Z

○ Measured
 ▲ Derived Profile

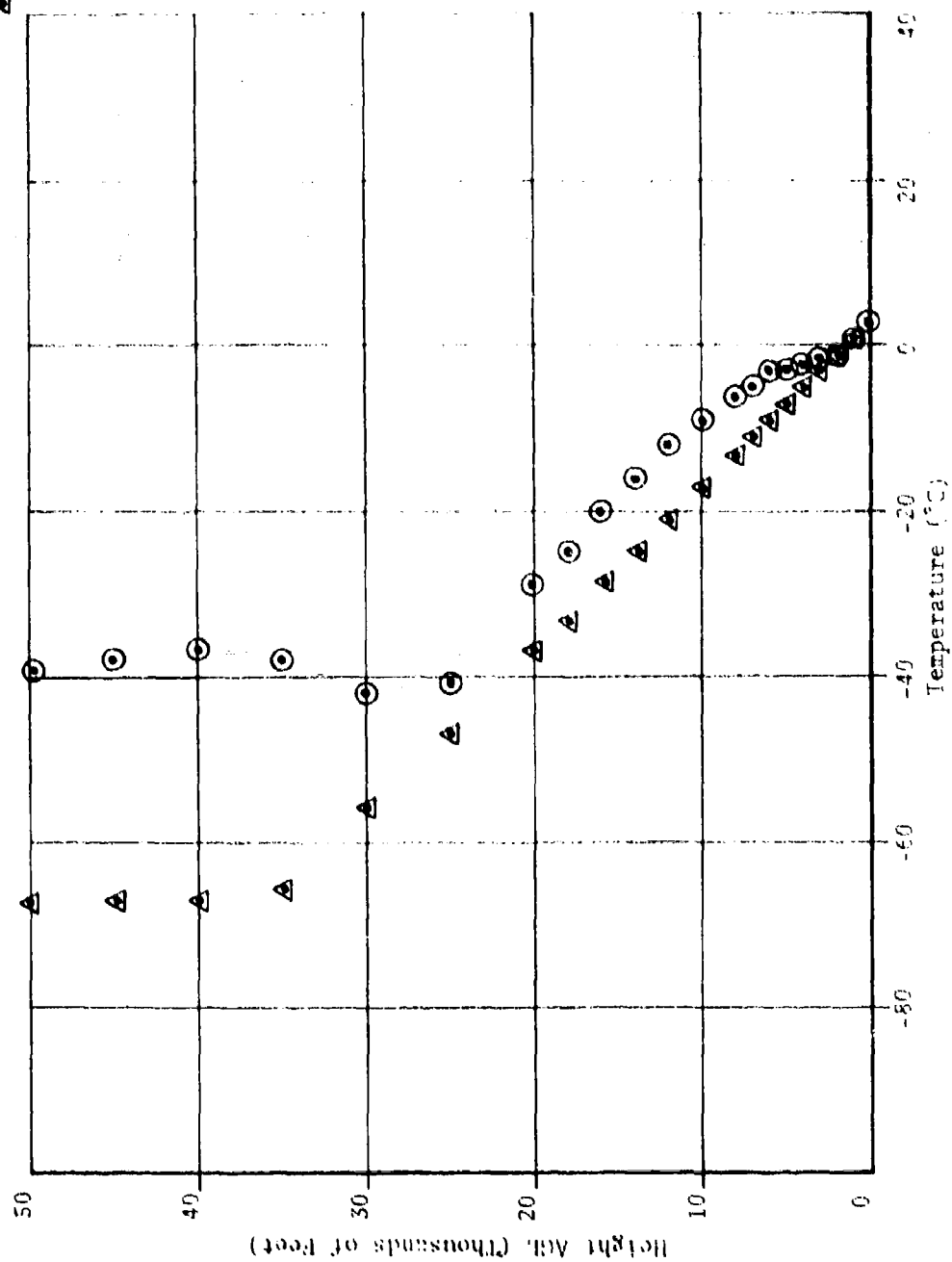


Figure 16. Temperature Sounding at Barrow, Alaska: 1 July 1976, 00Z

⊙ 4 January 1976, 00Z
 ▲ 1 July 1976, 00Z

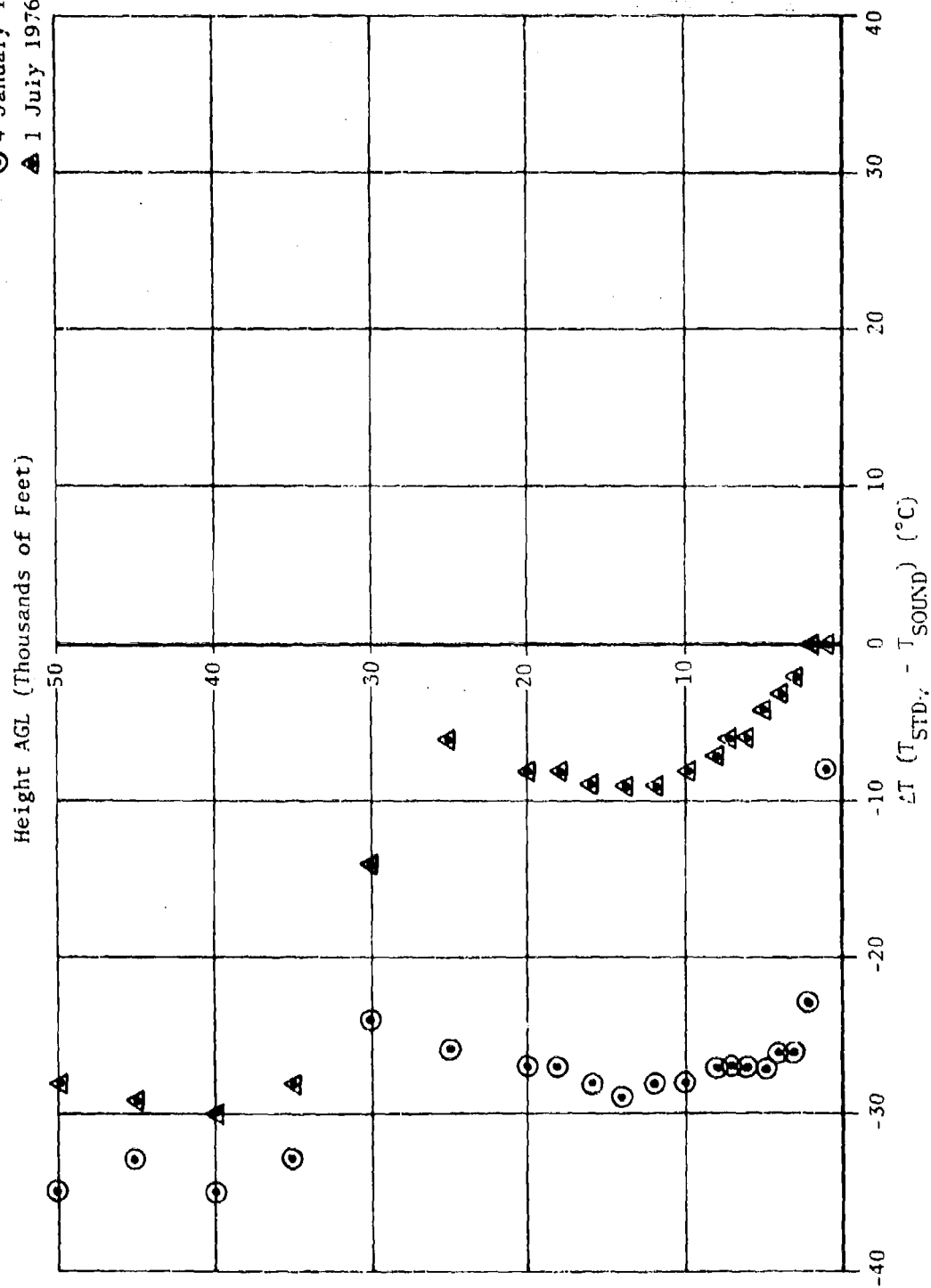


Figure 17. Temperature Differences Between Measured and Derived Soundings at Barrow, Alaska

○ Measured
 ▲ Derived Profile

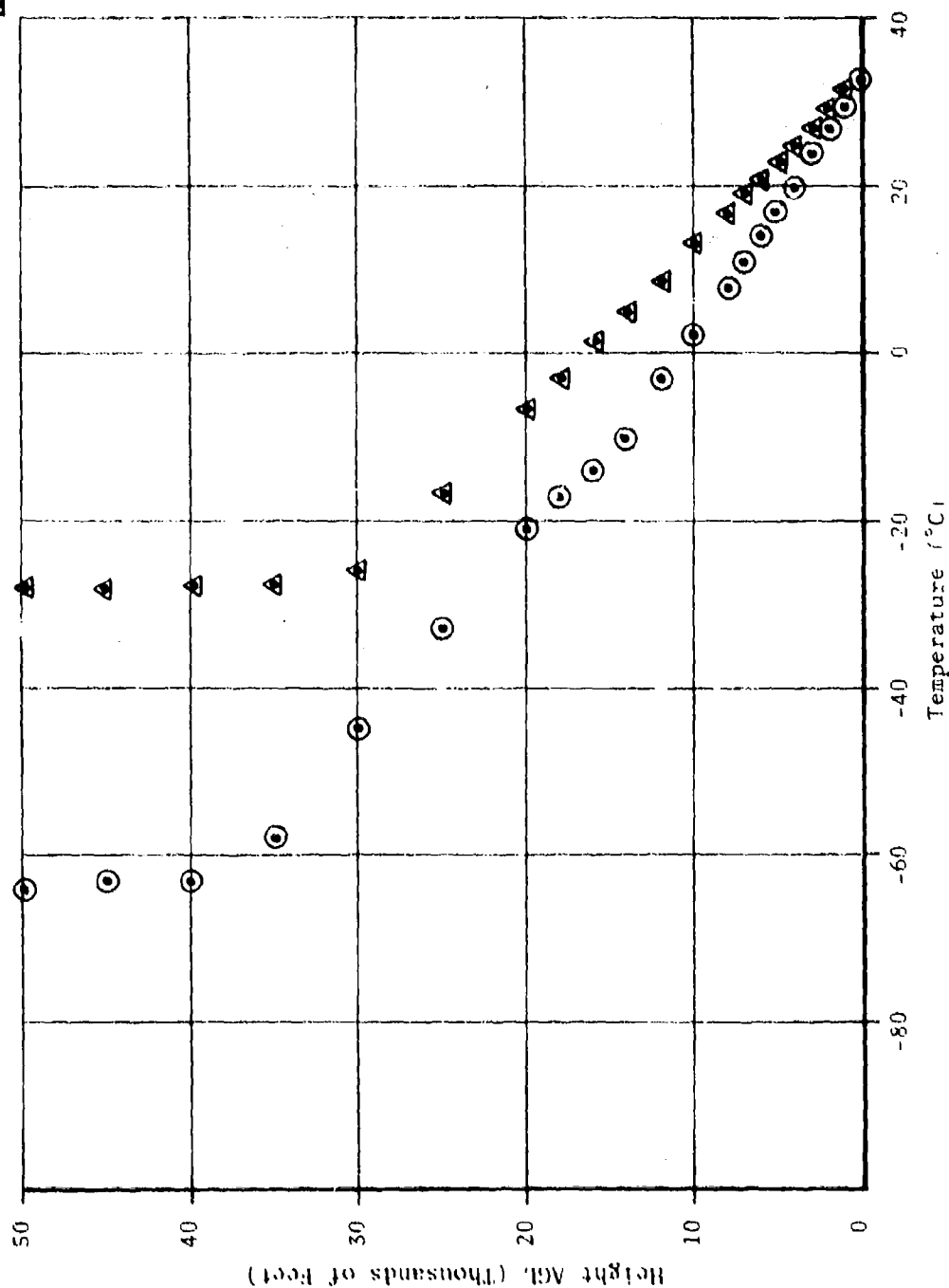


Figure 18. Temperature Sounding at Denver, Colorado: 5 July 1976, 00Z

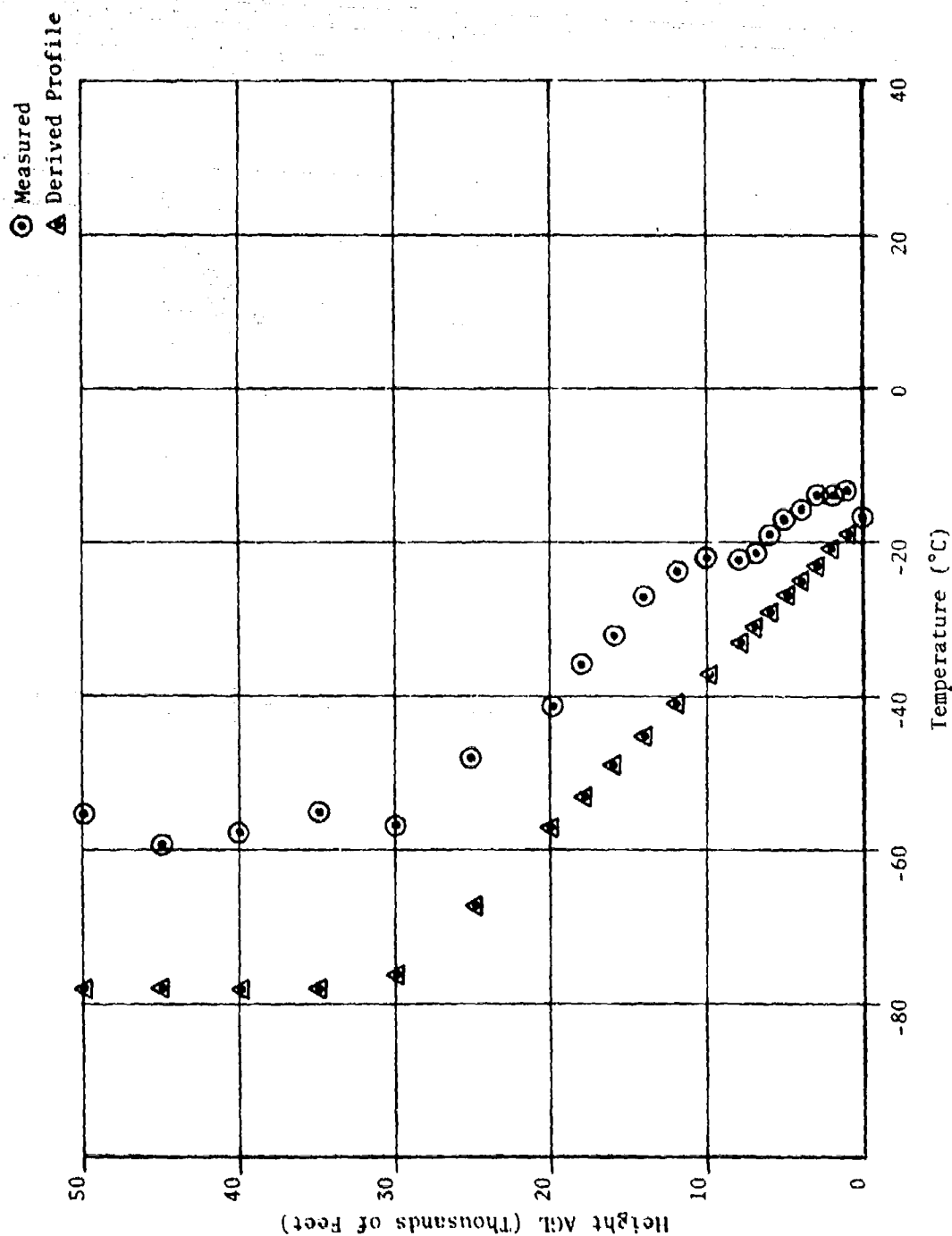


Figure 19. Temperature Sounding at Denver, Colorado: 3 January 1976, 12Z

○ 3 January 1976, 12Z
 ▲ 5 July 1976, 00Z

Height AGL (Thousands of Feet)

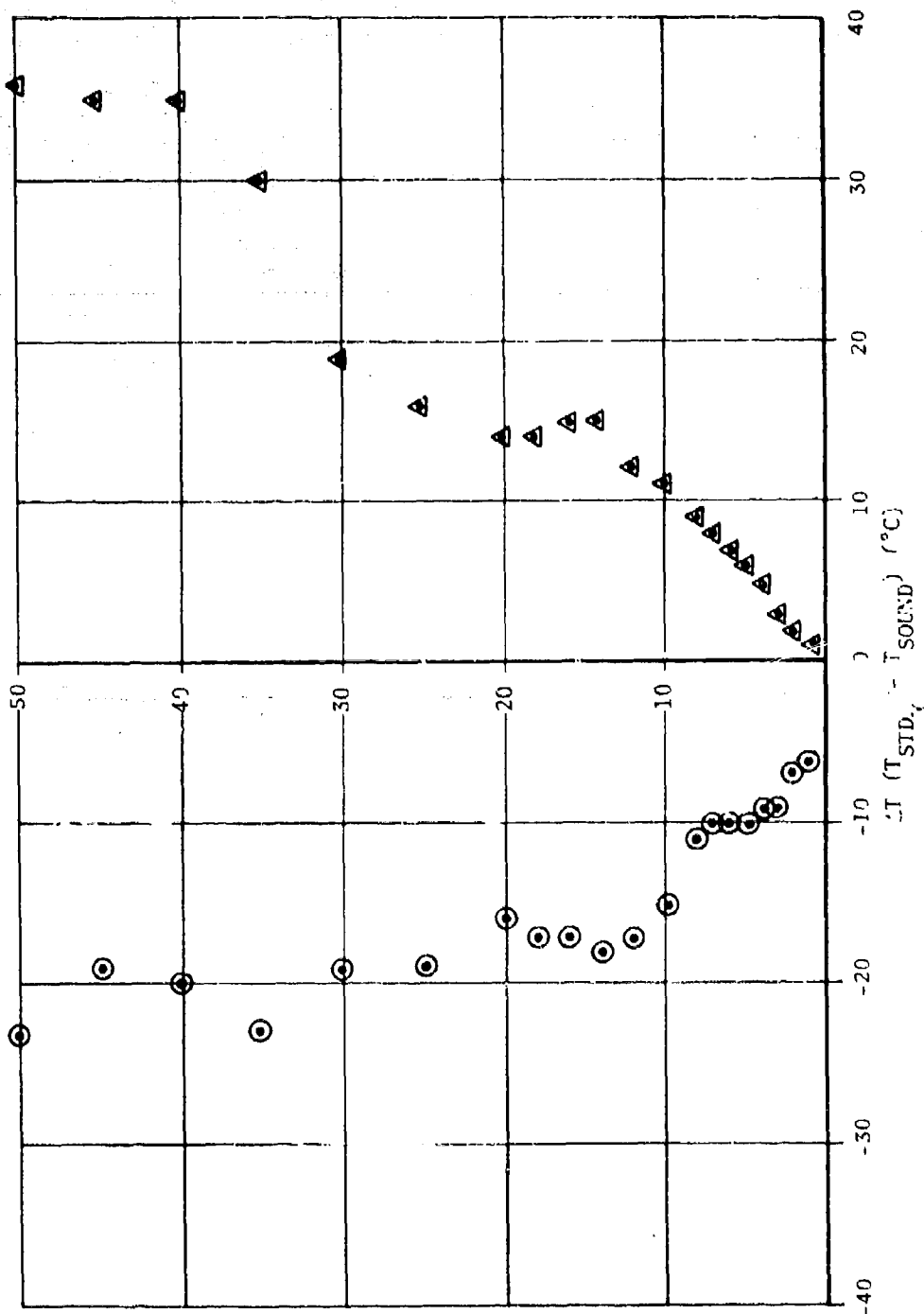


Figure 20. Temperature Differences Between Measured and Derived Soundings at Denver, Colorado

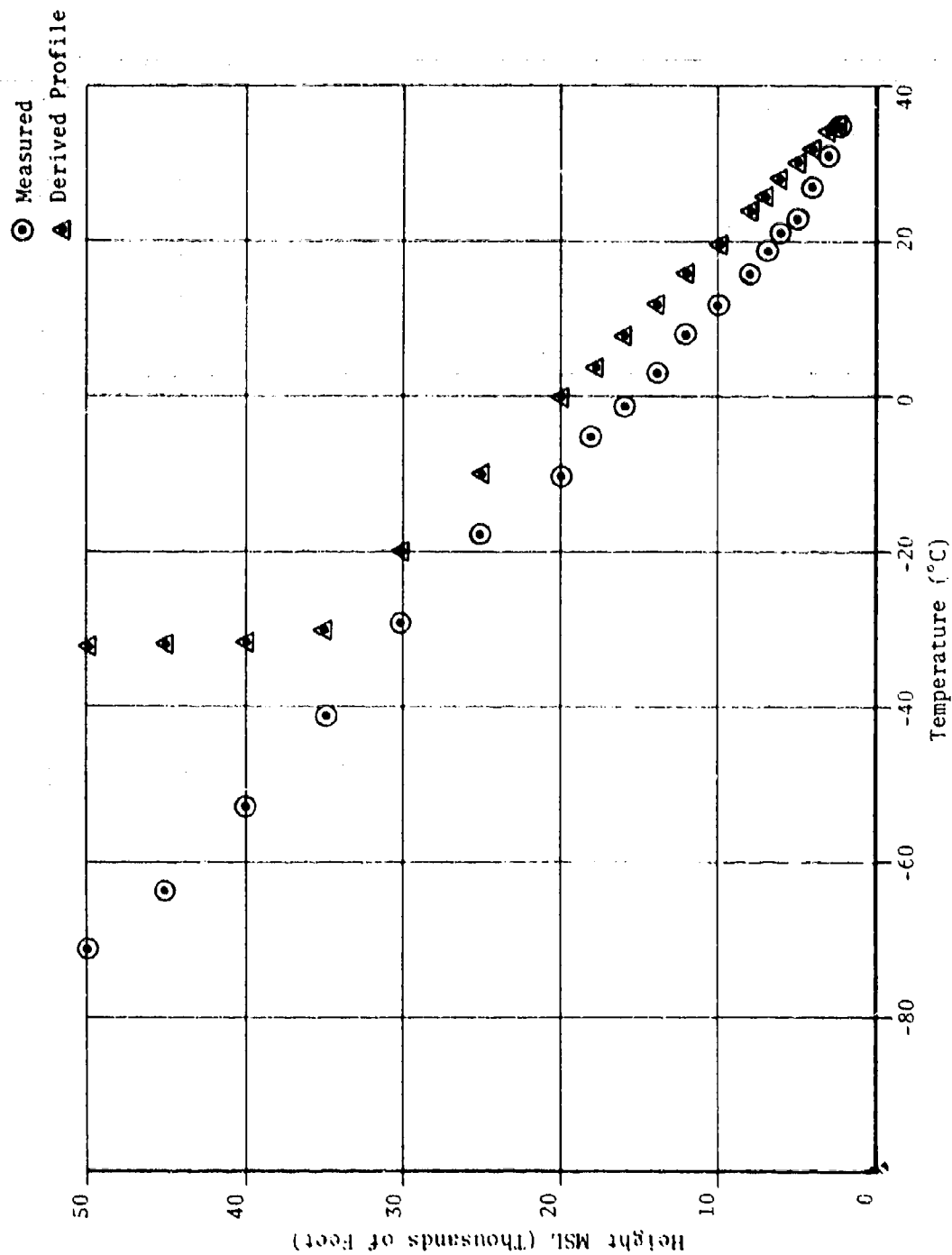


Figure 21. Temperature Sounding at Edwards Air Force Base, California: 22 August 1977, 10Z

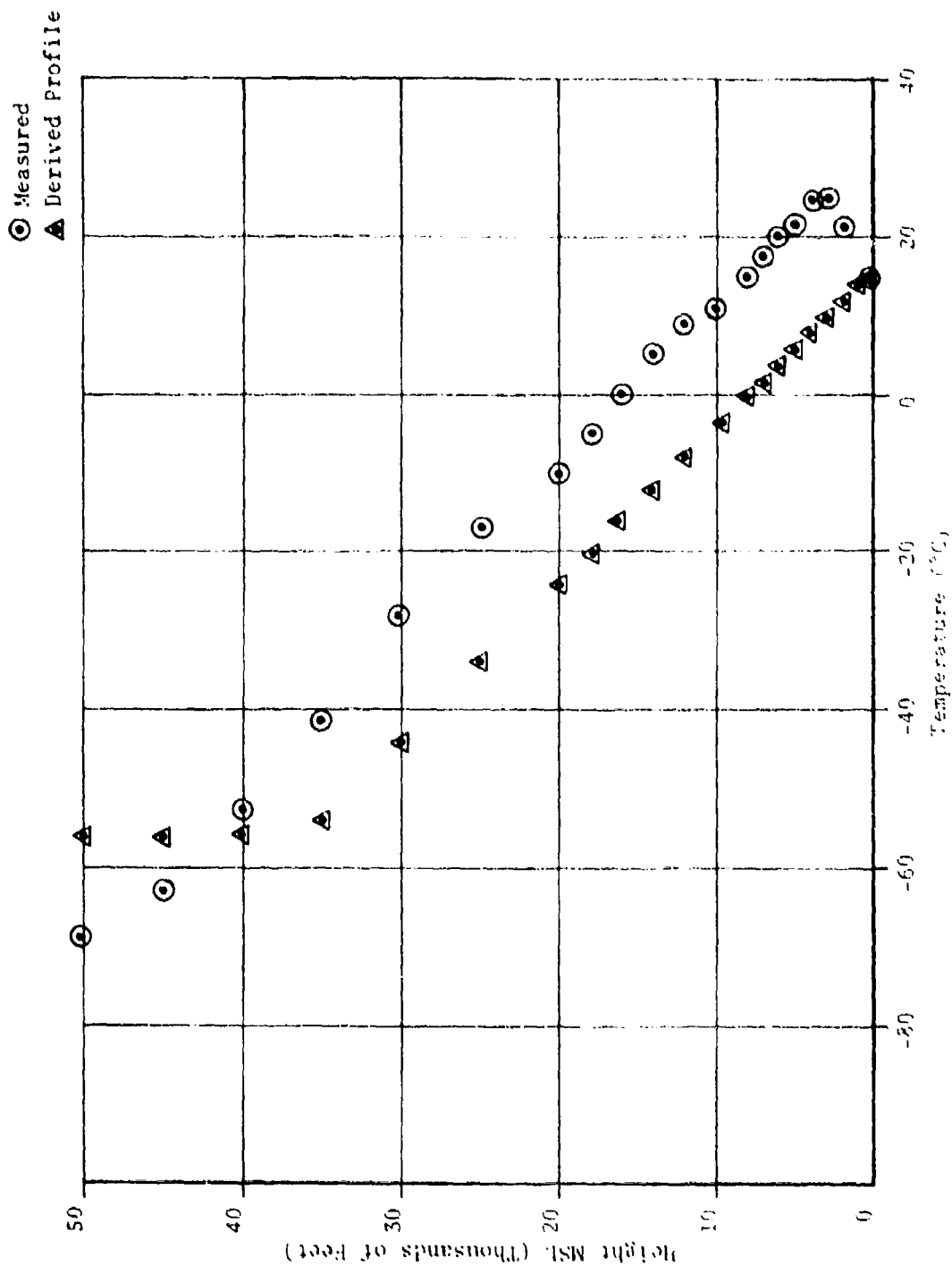


Figure 22. Temperature Sounding at Vandenberg Air Force Base, California: 22 August 1977, 12Z

Edwards AFB, CA
 22 August 1977, 10Z
 Vandenberg AFB, CA
 22 August 1977, 12Z

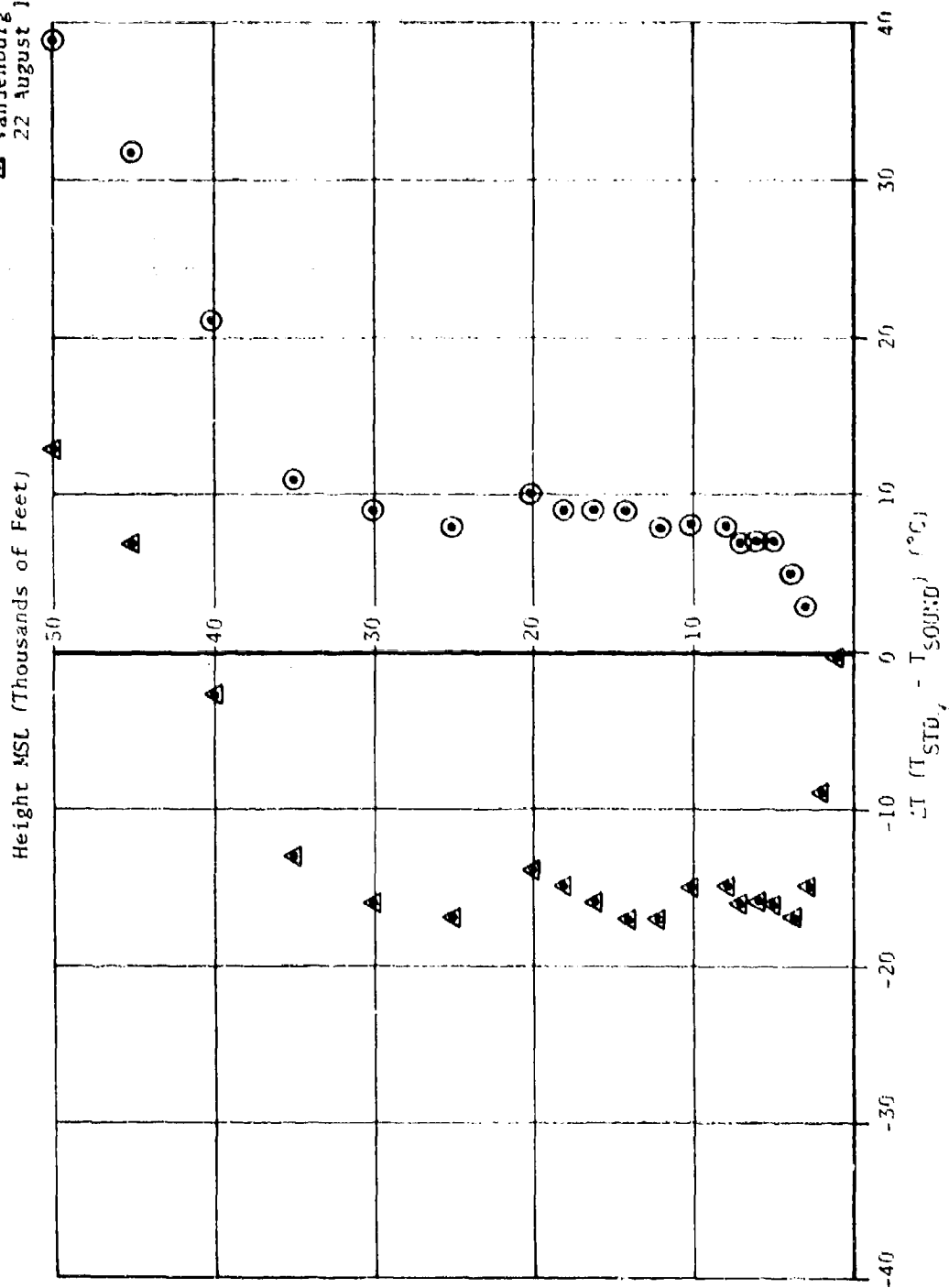


Figure 23. Temperature Differences Between Measured and Derived Soundings at Edwards Air Force Base/Vandenberg Air Force Base, California

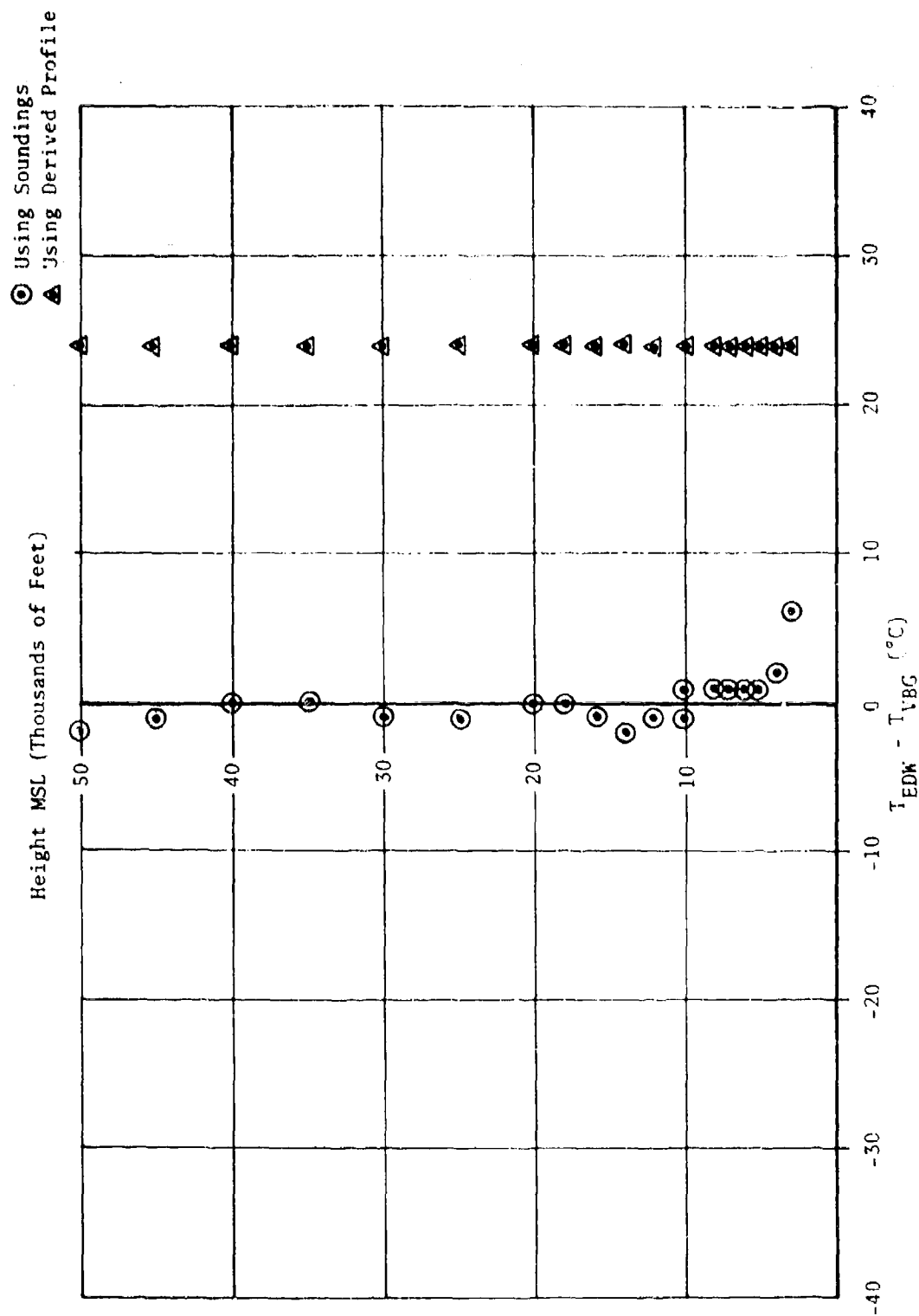


Figure 24. Temperature Differences Between Edwards Air Force Base/Vandenberg Air Force Base, California: Measured and Derived Soundings

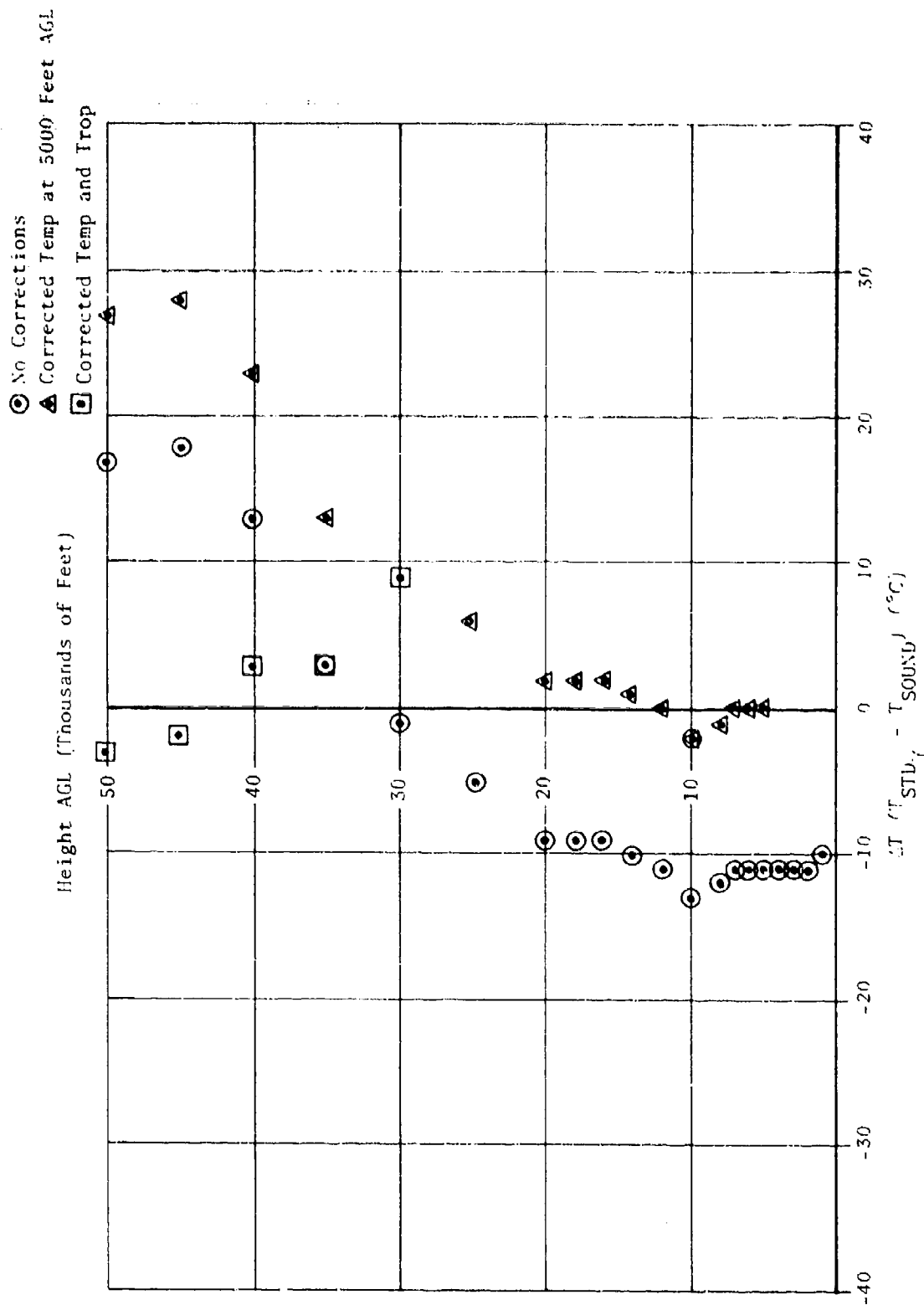


Figure 25. Temperature Differences Between Measured and Derived Soundings and Measured and Derived/Corrected Soundings at Mexico City, Mexico: 2 January 1976, 12Z

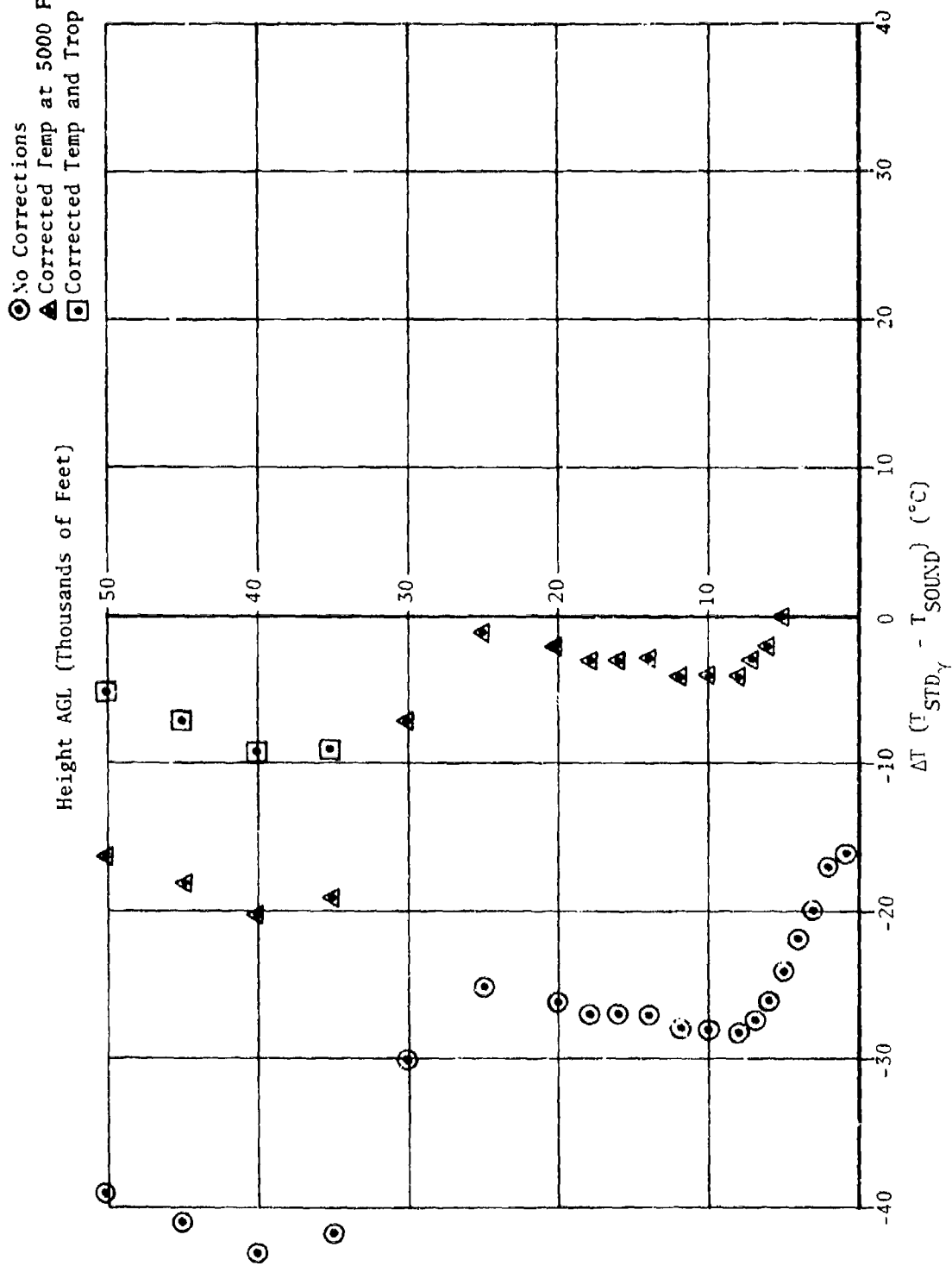


Figure 26. Temperature Differences Between Measured and Derived Soundings and Measured and Derived/Corrected Soundings at Fairbanks, Alaska: 3 January 1976, 12Z

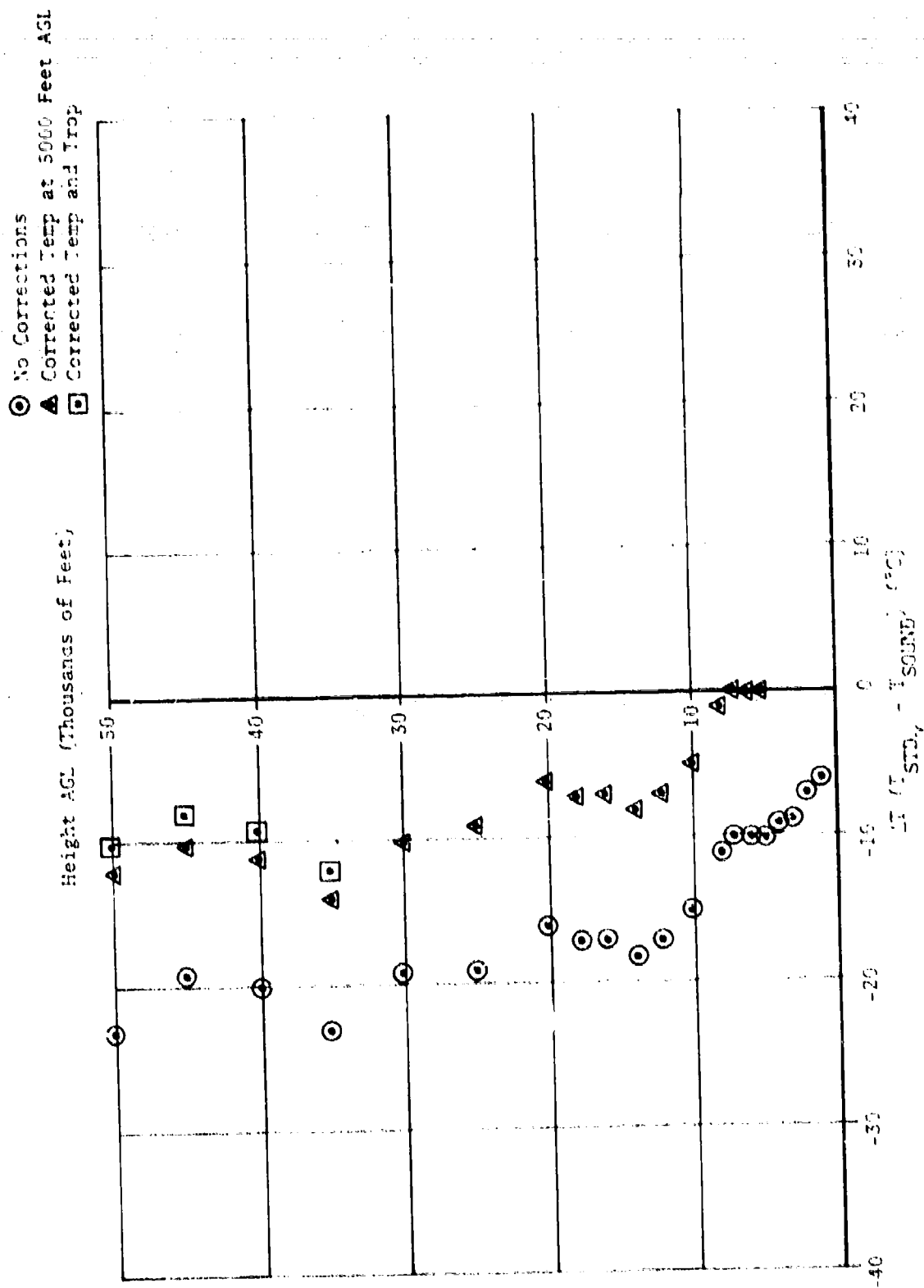


Figure 27. Temperature Differences Between Measured and Derived Soundings and Measured and Derived/Corrected Soundings at Denver, Colorado: 3 January 1976, 12Z

SECTION IV

CONCLUSIONS

Using a surface temperature along with the standard lapse rate to obtain temperatures at altitude gives unsatisfactory results in many cases. Although the locations analyzed were chosen to give large errors, these conditions are not unusual. Temperature inversions are a common occurrence at almost all mid-latitude locations during the winter. Strong inversions due to frontal systems can exist above the surface. Surface heating during the summer can lead to extremely large low-level lapse rates. All these factors lead to large departures from the standard lapse rate and cannot be taken into account by this method.

If the method assumes a standard tropopause height, more problems can result. Tropopause heights range from 25,000 to 60,000 feet at different locations and times, the lower value being appropriate to polar regions in winter and the higher value being appropriate for the tropics. Sometimes no distinct tropopause exists, or two tropopause levels are discernible. This can lead to large temperature errors at high altitude and abrupt reversals of the signs and magnitudes of the errors.

While the standard lapse rate can occur, it is by no means always realistic. If a simple method is needed to determine upper air temperatures, the corrected 5,000-foot temperature and tropopause height led to fairly good results in the examples tested. This method made a correction for surface effects and tropopause height and led to reduced errors in several examples. It should be remembered that even these corrections cannot account for higher level inversions and strong lapse rates which can exist at high altitude locations. However, this method or some modification may deserve further study.

REFERENCES

1. US Standard Atmosphere, 1976, sponsored by the National Oceanic and Atmospheric Administration and the National Aeronautics and Space Administration.